DEVELOPMENT OF AN INNOVATIVE MICROWAVE SOLAR DRYER FOR SEAFOODS

MASTER OF SCIENCE IN ENERGY TECHNOLOGY

M.Sc. Engg. (ET)

Submitted By

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DEVELOPMENT OF AN INNOVATIVE MICROWAVE SOLAR DRYER FOR SEAFOODS.

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APPROVAL

This thesis titled **"Development of an Innovative Microwave Solar Dryer for Seafoods"** submitted by **Sagar Talukder, ID-17MET024P**, Session: 2017-2018 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science (M.Sc.) in Energy Technology on **May 11th 2023**.

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I hereby declare that the work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the Thesis contains no material previously published or written by another person except where due reference is cited.

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DEDICATION

Dedicated to

My Father & Mother

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The author indebted to Almighty who enabled me with courage, strength, and patience to complete the research work and write up the thesis successfully.

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ABSTRACT

Drying is an ancient fish preservation method, involving a combination of heat and mass transfer to extend the life of fish materials. It is, however, an energy-intensive process that consumes approximately 20 to 25% of the energy used by the food processing sector. Developing innovative drying systems such as Microwave Solar Drying (MSD) and utilizing renewable energy such as solar energy in drying can be a potential solution for reducing conventional energy consumption in the drying process. An innovative solar energy-focused MS dryer system is developed and implemented in this Thesis. Microwave solar dryer optimization is necessary to create an efficient system that can influence drying conditions (e.g., relative humidity, flow rate, air temperature, MW power) to reach better efficiency and better-quality dried fish. An air duct is designed and connected to this microwave setup to accurately measure the velocity of additional controlled air (0.1 m/s, 0.11 m/s, and 0.12 m/s) supplied to the microwave from outside. The solar-assisted microwave dryer is carried out at different air velocities (0.1 m/s, 0.11 m/s, and 0.12 m/s) of 200 watts and 400 watts. This thesis also determines and compares the drying time and quality of some dried Bombay duck, silver belly, and silver Jewfish from both (MSD) and (TSD). Three marine fish samples obtained from sun and microwave drying were tested for Proximate composition and bacterial loads at the department of marine fisher's lab and poultry research lab training centre at Chittagong Veterinary and Animal Sciences University. All the fish samples were analyzed moisture, protein, crude fiber, crude fat, ash, calcium, and phosphorus according to AOAC (AOAC, 2016) methods. Microwave solar dryer (200-watt, 400 watt) drying yielded the best food content of Bombay duck, silver belly, Silver Jew fish compared to natural sun drying. Bacteriological study was conducted according to FDA BAM method. The bacterial loads of the solar-assisted microwave drying and traditional sun drying in Bombay duck, silver belly, and Silver Jewfish were 5.89×10^{6}cfu/g, 8.9×10^{5}cfu/g, & 4.96×10^{5}cfu/g (MSD) and 8.6×10^{7}cfu/g 5.6×10^{8}cfu/g, & 8.0×10^{6}cfu/g (TSD) respectively. In comparison to convective natural air drying, microwave solar drying produced fish with better product quality while using significantly less power. According to the study's findings, Microwave solar drying at 50°C with a pulse ratio of 3.0 reduced considerably drying time when compared to convective natural air drying, and it should be the preferred approach for drying to produce high-quality dry fish products with better physical (color and texture) attributes. This analysis found that the PMS drying time was approximately 5.20 hours, whereas traditional sun drying required an average drying time of 3-4 days (for Jewfish), 4-5 days (for silver belly), and 3-4 days (for squid) (for Bombay duck fish). The payback calculation in this study was based on the results of the HOMER simulation. The optimization produced a total Net Project Cost (NPC) of $2961 and an energy cost of 0.160 $/KWh or 16 BDT/KWh. And the payback is roughly one year and twenty days. In comparison to natural convective drying, the developed pulsed microwave sun drying significantly reduced drying time, increased product quality and color, and reduced energy consumption.

সারসংক্ষেপ

মাছকে দীর্ঘদিন ধরে রাখার জন্য একযোগে তাপ এবং ভর স্থানান্তরের মাধ্যমে মাছ সংরক্ষনের প্রাচীনতম কৌশলগুলোর মধ্যে একটি হল শুকানো। তবে, এটি তীব্র শক্তির প্রক্রিয়া এবং খাদ্য প্রক্রিয়াকরন শিল্পে ব্যবহৃত শক্তির প্রায় ২০ থেকে ২৫ % খরচ করে। পালসড্ মাইক্রোওয়েভ সোলার

ড্রাইয়িং এর মতো উদ্ভাবনী শুকানোর সিস্টেমের বিকাশে সৌরশক্তির মতো নবায়নযোগ্য শক্তির ব্যবহার, শুকানোর প্রক্রিয়ায় প্রচলিত ব্যবহার কমানোর সম্ভাব্য সমাধান হতে পারে। এই গবেষণায়, একটি উদ্ভাবনী সৌরশক্তি চালিত পালসড মাইক্রোওয়েভ সোলার ড্রাইয়িং সিস্টেম ডিজাইন এবং ব্যবহার করা হয়। মাইক্রোওয়েভ সোলার ড্রায়ার অপ্টিমাইজেশন একটি দক্ষ সিস্টেম তৈরী প্রয়োজন যা শুকানোর অবস্থাকে প্রভাবিত করতে পারে (আপেক্ষিক আদ্রতা, বায়ু প্রবাহের হার, বায়ুর তাপমাত্রা, মাইক্রেওয়েব পাওয়ার) যা ভাল মানের শুটকি তৈরীতে সহায়তা করে। বাইরের থেকে মাইক্রেওয়েভে সরবরাহ করা অতিরিক্ত নিয়ন্ত্রিত বাতাসের বেগ (০.১ মি./সে., ০.১১ মি./সে. ০.১২ মি./সে.) নির্ভুলভাবে পরিমাপ করার জন্য এই মাইক্রোওয়েভের সেটআপের সাথে বায়ুনালী ডিজাইন এবং সংযুক্ত করা হয়েছে।সৌরশক্তি সহায়ক মাইক্রোওয়েব ড্রায়ারটি ২০০ ওয়াট এবং ৪০০ ওয়াটের ভিন্ন ভিন্ন বায়ু বেগে পরীক্ষা চালানো হয়েছে।বর্তমান গবেষণাটি সোলার মাইক্রোওয়েভ ড্রাইয়িং এবং প্রাকৃতিক ভাবে রোদে উভয়ভাবে শুকানো লইট্যা মাছ, পোয়া মাছ, টেক চাঁদা মাছের শুকানোর সময়, গুণগতমান নির্ধারণ এবং তা তুলনা করার জন্য পরিচালিত হয়েছিল। তবে পিএমএসডি ২০০ ওয়াট ০.১ মি./সে. শুকানো মাছের মধ্যে ভাল খাদ্য উপাদান পাওয়া গেছে যেমন লইট্যা মাছে ময়েশ্চার, প্রোটিন, ফাইবার, চর্বি, ছাই, ক্যালসিয়াম এবং ফসফরাস ২১.৫০%, ৫৮.১৭%, ০.২৫%, ১৬.৬৭%, ১৪%, ২%, এবং ০.৬৭% যথাক্রমে যা প্রাকৃতিক ভাবে রোদে শুকানোর সাথে তুলনা করলে দেখা যায় যেমন ২৫%, ৪০.১৯%, ০.১০% , ৬.০৬% , ১৬% , ১.৩৭% , এবং ০.৪৯% যথাক্রমে। সোলার মাইক্রোওয়েভ ২০০ ওয়াট ড্রাইয়িং এ সিলবার বেলি (টেক চাঁদা) মাছের একই খাদ্য উপাদান পাওয়া যায় যথাক্রমে ৩৭.২৬%, ৪৬.৩৮%, ১.০০%, ৯.১১%, ৮.৮৭%, ২.৬০%, এবং ১.৪১% । সিলভার জুই (পোয়া) মাছে (সোলার মাইক্রোওয়েভ ড্রাইয়িং) এই খাদ্য উপাদান গুলি যথাক্রমে ২২.৬৮%, ৮৬.৮৮%, ০.৯৪%, ৬.২৫%, ২৬.৫৬%, ৫% , এবং ০.৪৮% পাওয়া যায় । সামুদ্রিক বোম্বে ডাক, সিলভার জুই, সিলবার বেলি মাছে সৌর শক্তিতে চালিত মাইক্রেওয়েভ ড্রাইয়িং এবং রোদে শুকানোতে ব্যাকটেরিয় লোড ছিল যথাক্রমে ৫.৮৯× $১০^{৬}$ সিএফইউ/গ্রাম, ৮.৯× $১০^{৫}$ সিএফইউ/গ্রাম, এবং ৪.৯৬× $১০^{৫}$ সিএফইউ/গ্রাম এবং ৮.৬× $১০^{৭}$ সিএফইউ/গ্রাম, ৫.৬ × $১০^{৮}$ সিএফইউ/গ্রাম, ৮.০× $১০^{৬}$ সিএফইউ/গ্রাম। সুতরাং রোদে শুকানো মাছের তুলনায় কম শক্তি সম্পন্ন সোলার পালসড মাইক্রেওয়েভ ড্রায়ারে শুকানো মাছের গুনমান ভাল ছিল। এই সমীক্ষার ফলাফলের উপর ভিত্তি করে, ৫০ ডিগ্রী এবং পালস রেশিও ৩.০ পিএম এস ড্রায়ারে শুকানোর সময় প্রাকৃতিক ভাবে রোদে শুকানোর তুলনায় যথেষ্ট পরিমান কম ছিল এবং উৎপাদিত গুনগত মানের শুটকির (রং, এবং গঠন) বৈশিষ্ট্যর কারনে সোলার মাইক্রোওয়েভ ড্রায়ারে মাছ শুকানো পছন্দের পদ্ধতি হওয়া উচিত। এই গবেষণায় দেখা যায়, পিএসএম শুকানোর সময় ছিল ৫.২০ ঘন্টা, প্রাকৃতিক ভাবে রোদে শুকানোর গড় সময় ছিল ৩-4 দিন পোয়া মাছ, ৪-৫ দিন চাঁদা মাছ, এবং ৩-4 দিন লইট্যা মাছ শুকানো। এই গবেষণায় হোমার সিমুলেশনের ফলাফল পে-ব্যাক পিরিয়ডের জন্য ব্যবহার হয়েছিল অপ্টিমাইজেশন থেকে প্রাপ্ত ফলাফলে মোট নেট প্রজেক্ট খরচ $2961 এবং প্রতি এর্নাজিতে খরচ .০১৬ $/কি.ও.ঘ. বা ১৬ টাকা / কি.ও.ঘ. এবং পরিশোধের সময়কাল প্রায় একবছর বিশ দিন। সামগ্রিকভাবে উদ্ভাবিত নবায়নযোগ্য এনার্জি বেইসড মাইক্রোওয়েভ সোলার ড্রায়ারে শুকানোর ফলে সময়, উন্নত গুনমান, কালার বৈশিষ্ট্যের কারনে প্রাকৃতিক ভাবে রোদে শুকানোর তুলনায় ভাল প্রতীয়মান হয়।

LIST OF PUBLICATIONS

1. Sagar Talukder, Md. Tazul Islam, Saiful Islam, and Avijit. Talukder "Assessment

on Proximate Composition and Microbial Characteristics of Commercially Available Marine Dry Fishes of Cox's Bazar, Bangladesh", ICMERE 2021, Chattogram, 12-14 December

2. Sagar Talukder, Md.Tazul Islam, Md. Saiful Islam and, Syed Md. Ikram "Comparative studies on drying characteristics, proximate composition, and microbial characteristics of marine silver belly fish.", ICMIEE 2022, Khulna, 22-24 December.
3. Sagar Talukder, Md. Tazul Islam, Md. Saiful Islam, and Syed Md. Ikram "Experimental Investigation of proximate Analysis and microbial characteristics of Bombay duck fish dried with the solar-powered microwave.", PESGRE-2023,17-20 December,2023, Trivandrum, Kerala, INDIA (In Revision)

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LIST OF ABBREVIATIONS

PMSD	Pulsed Microwave Solar Dryer
IMCD	Intermittent Microwave Convective Dryer
PV	Photovoltaic

RH	Relative Humidity
REB	Rural Electrification Board
CD	Convection Drying
MWC	Microwave Convection Drying
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
H_2SO_4	Sulfuric Acid
HCL	Hydrochloric Acid
NaCL	Sodium Chloride
NaOH	Sodium Hydroxide
CFU	Colony Forming Unit
SPC	Standard Plate Count
HOMER	Hybrid Optimization Model for Electric Renewable
NREL	National Renewable Energy Laboratory
^0C	Degree Celsius
AOAC	Association of Official Analytical Chemists
hr	Hour
TPC	Total Plate Count

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND AND MOTIVITION

Fish is not only the main source of animal protein but also an unrivalled source of nutrients like omega-3 fatty acids, calcium vitamin D and iodine, it is the important source of animal protein over the animal protein available in the tropics and research shown that the protein from fish have good health effect [1,2]. The omega-3 fatty acids (n-3PUFA) are known to be beneficial to human health in conditions like metabolic syndrome, diabetes, and arteriosclerosis, obesity, as well as to promote neural and brain development [3]. Research suggests that, in addition to reducing the risk of heart disease, the oil found in seafood may also reduce the risk and improve the effects of other chronic conditions, including rheumatoid arthritis, several cancers, asthma, psoriasis, and vision problems. Fresh fish deteriorates quickly. Drying fish is a method of preserving fish that removes water or moisture from the fish. This inhibits microorganism growth and prevents the process from decaying. To decrease this massive loss, promote food security, and combat hunger, proper fish processing must be emphasized. Drying is one of the simplest and oldest techniques of processing and preserving food, as it keeps food from spoiling due to microbial growth. It extends shelf life, reduces weight and volume, lowering packing, storage, and transport cost, and allows food to be stored in an ambient environment [4]. However, it is likely the most energy-intensive of the major manufacturing processes [5], accounting for up to 15-20% of total industrial energy consumption [6]. Furthermore, drying alters food quality by causing discoloration, organoleptic loss, textural changes, nutritious degradation, and physical appearance and shape changes [7]. For many years, researchers have worked to improve energy efficiency and quality of products in food drying. The Pulsed Microwave-Solar Dryer (PMSD), also known as the Intermittent Microwave Convective Dryer (IMCD), is a method for improving both energy efficiency and quality of products [4]. Although there have been some experimental studies of microwave dryers, optimization of processing parameters as well as the integration of solar energy to power the system have remained undeveloped.

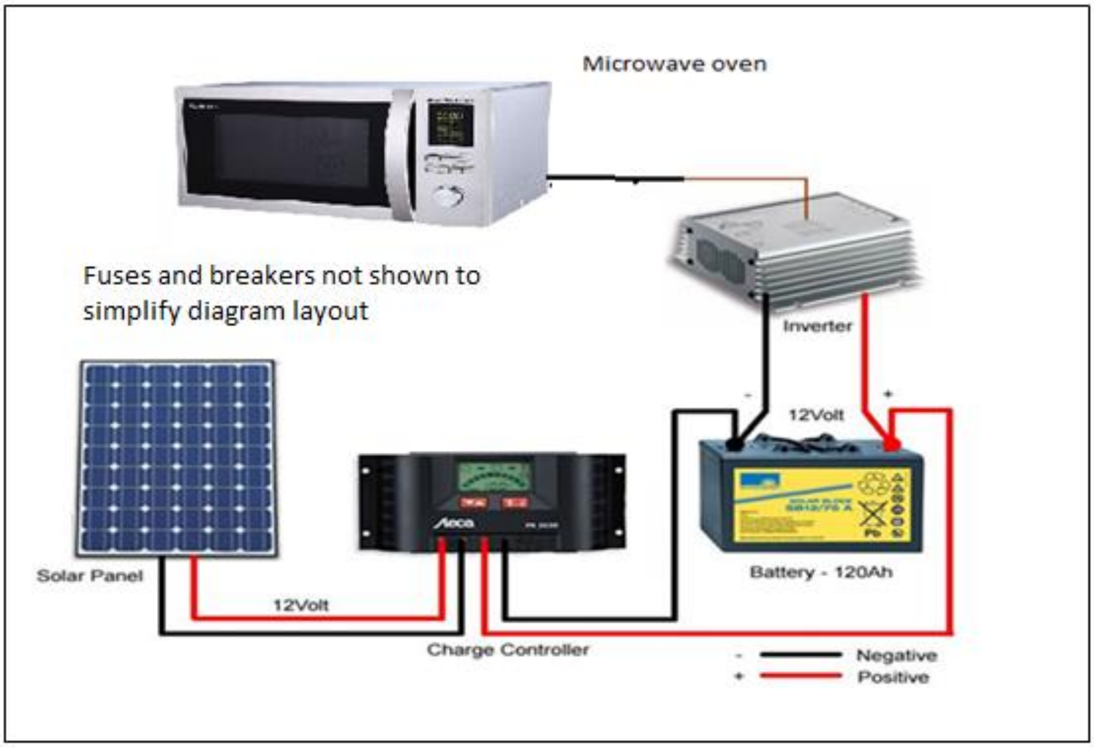

Figure 1.1: Schematic Diagram of PV Module System

Figure 1.1 shows the schematic diagram of PV module system. The optimization of microwave solar dryers is essential to develop an intelligent system that can manipulate the drying conditions (e.g., air temperature, flow rate, RH, Microwave Power) in order to achieve higher energy efficiency and better quality. Therefore, this research aims to develop a comprehensive microwave solar dryer setup to optimize the process of food preservation by using renewable energy sources such as solar energy.

1.2 SOLAR ENERGY IN BANGLADESH

Bangladesh has a plentiful supply of renewable energy sources. Thus, if alternative energy sources are used properly, energy is not an issue at all. Solar energy, according to solar power, is used to generate electricity. Bangladesh has an abundance of solar energy. Solar-powered electricity generation is environmentally friendly. Solar energy development should be a primary concern for Bangladesh inside the twenty-first century [8]. Currently, the national grid serves only half of the country's nearly 10,000 rural markets and commercial centers, creating an excellent market for centralized solar photovoltaic plants. Currently, private diesel Genset operators serve in the majority of off-grid rural markets, and 82% of them are involved in marketing SHS in nearby areas if favorable financial arrangements are available [9]. According to A.K.M.S. and Islam [10], various government administrative offices, non-governmental offices, health care facilities, schools, banks, and police stations are able to operate throughout the country. Off-grid offices either use traditional lighting (lanterns, candles, kerosene wick lamps, etc.) or run their own diesel generators. These offices have separate electricity budgets and can be easily served by solar photovoltaic applications.

In contrast, Islam.M. [11] stated in his research article that Bangladesh has the potential to meet a significant portion of its future electricity demand cost-effectively through the use of renewable generation technologies, potentially adding as much renewable capacity as the country's current overall electric power capacity. Many parts of the country have favorable solar conditions, and there are numerous applications that could be cost-effective. In his article, Islam also stated that in order to realize the enormous potential of renewables, Bangladesh should develop a strategy framework that allows and inspires private investors to invest in renewable energy projects.

Bangladesh receives plenty of solar irradiance throughout the country. The average daily solar radiation ranges from 4 to 6.5 kWh/m2. The month of March-April has the most radiation and the month of December-January has the least. Solar photovoltaic and thermal applications in the country have a promising future. A solar PV system is a promising new option for supplying electricity with high-quality light, dependable service, as well as long-term sustainability [12].

Thus, it is clear from the past studies that solar energy has the potential to also be usually applied if additional studies are carried out. Solar Power Bangladesh is geographically situated in a favorable position (between 20^0 34′ to 26^0 38′ north latitude) for harnessing sunlight, which is abundant for the majority of the year with the exception of the three months June-August, when it rains heavily. The amount of solar energy available in Bangladesh is high, ranging from 4 to 7 kWh/m2/day, which is sufficient to meet the country's demand. Rural people are increasingly accepting of photovoltaic solar (PV) systems for supplying electricity to households as well as small enterprises in rural off-grid areas. The Rural Electrification Board (REB), a government organization, has been working to commercialize solar power electrification of rural homes, businesses, and irrigation systems. IDCOL, a government-owned organization, has distributed some

SHS through its NGOs partners. Due to the higher cost of production, it must travel a long distance to become commercially able to compete.

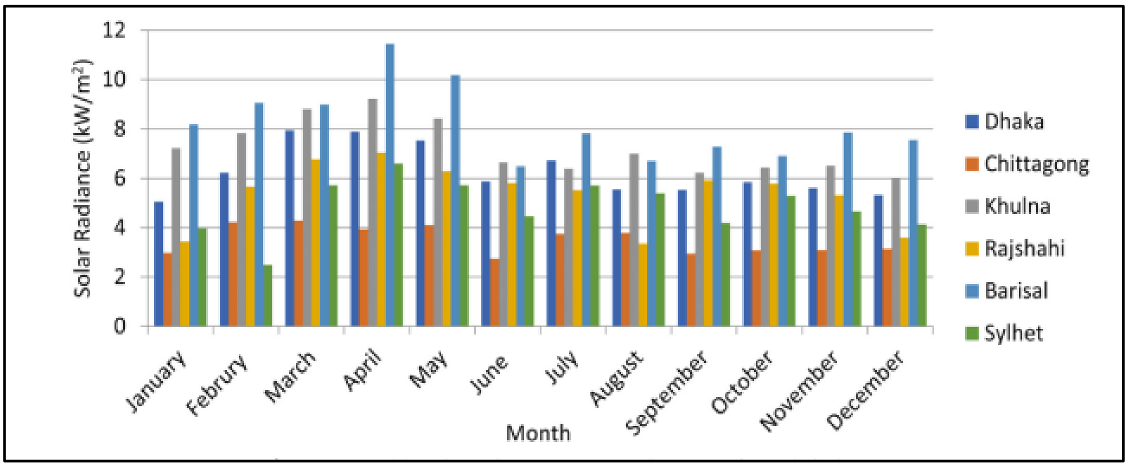

Figure1.2: Monthly Solar Radiation in Various Division of Bangladesh [13]

However, it is gradually gaining popularity in rural areas of Bangladesh, and the government has implemented numerous schemes to subsidize it. The government intends to build solar panels with a capacity of 510 MW [14]. Figure 1.2 is demonstrated the month to month normal sun oriented radiation profile in Bangladesh . Day by day normal sun based radiation changes 4 to 6.5 kwh per square meter on average. The highest levels of radiation are available during the months of April and May, and the lowest levels are available during the months of December and January. As indicated by IDCOL , the absolute limit of sunlight based vitality based estabilshment in Bangladesh has all the eramarks of being 20.75 MW .The sun is noteworthy considering the upward trend of the quantity of home system establishments in Bangladesh [15].

1.3 IMPORTANCE OF FISH DRYING

Fish is eaten as food in almost all parts of the world and it is common among the general peoples due to its affordability, taste, nutritional value and palatability. It is well recognized as a superior protein source to other animal proteins available worldwide, as well as an essential component in the preservation of good health [16]. Fish and other fish-related aquatic goods account for at least 20% of global protein consumption, with developed countries holding the largest dependency[17]. In Bangladesh, It contributes 60% of the population's total dietary consumption of animal protein. [18]. Fish is filled with low-fat high-quality protein, essential fats (omega-3 fatty acids), Vitamins (A, D and B) and a great source of minerals (calcium, Iodine, Zinc, Iron, and selenium). It also helps to fix an unbalanced diet by substituting some dietary properties that are unavoidable [19]. Marine fisheries sector contributes around 16.15% of the country's total fish production and the Bay of Bangle has nutrient rich water which is considered as a suitable habit for fish production. The majority of people on the globe tend to eat fish that is still fresh. However, since raw fish is an extremely perishable product, and quality losses can occur quickly after capture, it is difficult to supply fresh raw fish in long-distance areas of the region [20]. It may deteriorate quicker than other foods due to enzymatic degradation, chemical changes, and microbial growth, which might quickly render it unfit for human consumption. Fish begin to spoil after a few hours of being caught, and the pace of deterioration is based on the species and the surrounding environment [21]. Depending on species and the technique of capture, it typically takes fish 10 to 12 hours to totally deteriorate [22].

Since drying totally prevents physiological, microbial, and enzymatic deterioration of fish, the consistency of dried fish is very large [23]. In Bangladesh as a whole and in the coastal region, drying is the most significant fish processing sector in both terms of value and volume. Exports reached 3144 mt of dried fish for 425.9 million takas during the 2018–2019 fiscal years. [18]. Fish drying is the most cost-effective way of fish preservation [24]. Both the domestic and foreign markets for dried fish are encouraging. Bangladesh receives a large amount of foreign exchange per year by selling dried fish [25]. Traditional sun drying is an easy, inexpensive and cost-effective technique, but it also has many disadvantages because it is highly dependent on weather conditions that are beyond the control of fish processors. Along with sunlight the other two important factors are relative humidity (RH) and wind velocity are necessary for fish drying Dust, soil, bacteria, and other contaminants polluted the goods due to unsanitary treatment of fish throughout drying. Slow drying, inclement weather and potential deterioration due to microbial biochemical reactions all contribute to low-quality dried fish. Insect and fly infestation is another big issue associated with fish drying [26].

Figure 1.3: Traditional Fish Drying Process.

Figure 1.3 shows the Traditional Fish drying process. Some marine fish species such as Bombay duck, Jew fish pomfret, pink perch, Croakers, Mackerel, Soles, Ribbon fish, Seer fish, silver bellies, Anchovies, Shrimp, etc, are mainly used for sun drying in Bangladesh. Among them Bombay Duck, Silver jewfish, Ribbon fish is very important for artisanal fishery because of its abundance, as well as its suitability for drying. Dried Bombay duck, silver jewfish, and Ribbon fish are highly prized foods in Chittagong district, where they are plentiful [27]. Dried fish is a major commercial product in Bangladesh's southern region. Sunlight is the traditional energy source for drying fish. Fish drying is a traditional process. However, sun-drying has several drawbacks, including a long drying period in non-sterile conditions, as well as poor handling throughout processing, resulting in a low-quality and undesirable finished product [28]. When biological goods are dried using various conventional thermal techniques such heated air drying, vacuum drying, sun drying, and freeze drying, the drying rates are low throughout the rate-decreasing phase, and the finished product suffers from unwanted thermal damage [29]. The advantages of microwave drying include quick and relatively equal heating, shorter working times, great thermal effectiveness, space utilization, sanitary settings, energy efficiency, accurate control systems, quick start-up and ,shut-down situations, and high-quality finished products [30,31]. Customers in developed countries have become more conscious of the effect of nutrition on health and well-being in recent years [32]. As a result, there is a greater demand for high-quality, low-fat foods that satisfy nutritional needs, provides medical benefits, and lowers the associated with particular illnesses; extra advantages could include an extended shelf life, cost-effective preparation, improved taste, and ease of preparation. [33].

Microwave processing is one of these substitute technologies, and it has been successfully used for a wide range of chemical industrial operations as well as, more recently, for a variety of process units in the food manufacturing, such as thawing/tempering, dehydrating/drying, cooking, blanching/baking, sanitizing, or pasteurizing of various food matrices. Microwaves are non-ionizing electromagnetic waves with frequencies ranging from 300MHz to 300GHz. The ISM frequency lies among infrared rays and television and radio waves. It is more or less constant and is near to 2.45MHz. When employed, thermal generation or volumetric heating occur simultaneously with convection and condition phenomena, albeit at very distinct time frames. As a result, when compared to traditional thermal methods, in general, microwave heating has a number of benefits, including quicker heating times, more energy efficiency, a lower environmental impact, more accurate equipment controls, selective heating, and increased nutritional quality of the finished goods. [34]. Sea fish is currently primarily dried using hot air and conventional natural methods. Additionally, several innovative drying techniques have been created and applied to aquatic products, including microwave drying [35] vacuum freezing drying [36], hot pump drying, and infrared drying . However, almost every procedure has a drawback. Natural drying, for example, is greatly influenced by external factors, resulting in low production efficiency. It is challenging to adjust to the growing demands of the safety and quality of food systems to the unsanitary circumstances [37]. The drawbacks of hot-air drying include a lengthy drying period, high energy usage, browning of the product, potential nutrition loss, and deterioration of color and texture quality. [38]. In microwave drying, high-frequency electromagnetic frequencies are employed to heat the material, and this energy is converted directly to thermal energy inside the substance

[39]. When compared to other dry procedures, microwave drying is a very effective internal heating method that drastically cuts drying time and maximizes energy savings. In this study, an improved method involving high-power microwave heating has been established. The process of dielectric heating, which involves a high-frequency electric field interacting with the fish, is an efficient way to turn electrical energy into heat for drying fish.

1.4 MICROWAVE DRYING

Microwave drying is an innovation in drying technology that chooses to follow the convective drying, and it is likely the first method introduced that doesn't require direct contact between the source of heat and the product sample [40 Microwaves are electromagnetic with a frequency range of 300 MHz to 300 GHz. Because water molecules in wet material are electric dipoles, microwave drying is possible. Because they have a positive charge at one end and a negatively charged at the other, they rotate as they try to align themselves with alternating electrical field induced by the magnetron. This molecular movement generates heat through friction as the rotating molecules collide with and move other molecules [41]. During microwave drying, the balance between the energy produced by the water dipoles inside the microwave field and the energy soaked up by the moisture dipoles in the microwave system and the energy soaked up by the water molecules evaporated from the material's surface determines the temperature of the dried materials [42]. In microwave drying, the impact of different wavelength, power input, and energy efficiency are the key areas of focus. However, due to both technological and financial limitations, there are still just a few applications in the market for microwave drying. Nowadays, microwave technologies, such as a microwave oven, is a typical household equipment used to cook up their food. Microwave drying has the disadvantage that it uses expensive electric power, which makes it less cost-effective than other methods. In addition, compared to convection hot air and SD, microwave drying has still been regarded as a relatively young technology with a number of unresolved technical issues. Consequently, much study is required to enhance the technique before it is used extensively on an industrial platform [43]. Rapid mass transfer caused by a high-power input may induce puffing, and power input determination varies with the nature of the product are problems of microwave drying [44]. Researchers are interested in the microwave drying approach because it considerably improves the drying characteristics for the period of falling rate by passing through the sample and into the internal layer of the product. Because to the variation in polarity and the absence of friction losses during energy transmission, this method has been given extra credit for selectively heating water and organic materials. Also, when the setting is done properly, microwave drying eliminates localized hot spots/heating in the sample, retaining a superior physical look, texture, and improved retention of the nutrient [45].

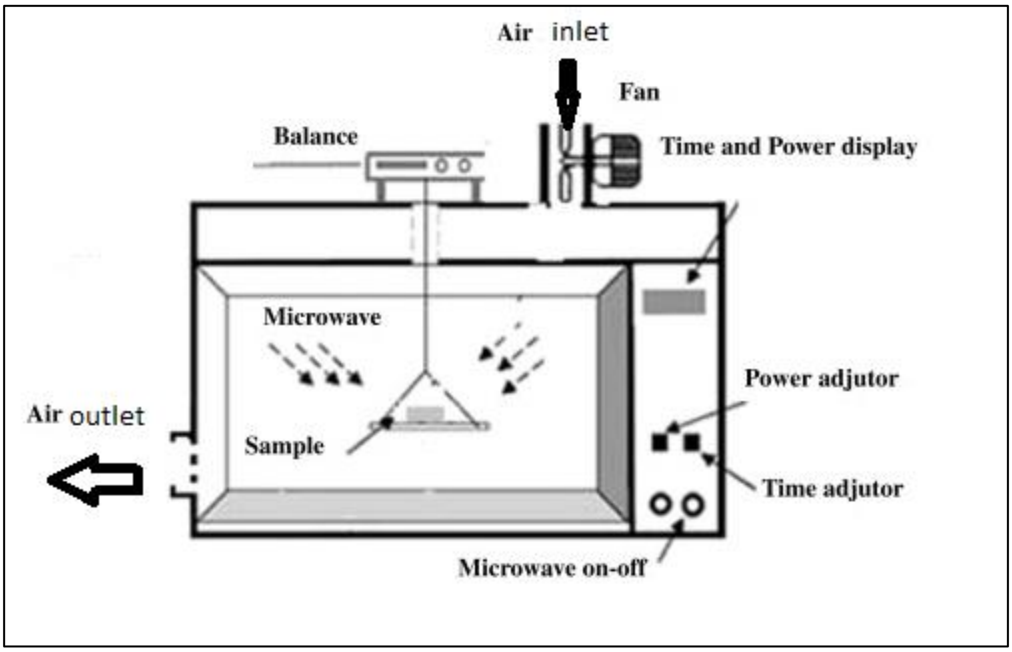

Figure 1.4: Microwave Drying System [46]

Figure 1.4 shows the Microwave drying system. When the material does not vary its location in the microwave field, the inhomogeneity of the microwave system may result in hot places within the material. This may result in burning towards the end of the drying process [46]. As a result, one alternative is to use microwave drying in conjunction with a vacuum drying equipment. This combination has been shown to be successful in many prior studies involving the drying of herbs and fruits in terms of maintaining active components while also increasing the quality of final dried items. [47]. The high rate of drying and consistent drying of microwave drying make it an effective technique for food material drying. During the decrease in rate period (the final stage of drying), microwave drying might accelerate the drying process. Conventional drying causes the samples to shrink and has a low surface moisture level during the falling rate period. However, due to volumetric heating after microwave drying, vapors are produced in the interior of food products. Therefore, microwave drying can stop food items from shrinking and it can be used in combination with other drying techniques to increase drying effectiveness and product quality. High quality food ingredients were created using a combination of microwave heating techniques, such as microwave-hot air drying.

1.5 NUTRITIVE CHARACTERITICS OF DRIED FISH

Dried fish is very important part of fishery products in Bangladesh. It is the source of low-cost high-quality protein to the population with low income. Nutrition is the main part in the consumption of fish product or Seafood [48]. In present time, people are conscious about the health risk and nutritional issues and people of developed countries are even more concern about it [49]. The food value of dried fish is well established by researcher [50]. The average protein content of most of the raw fish is about 18-20% but dried fish shows a very high amount of protein (about 40-70%)

According to Oladipo.I.C [51] the protein, content in fresh Clarias ariepinus and Oreochromis niloticus respectively 17.50% and 16.63% but in dried fishes the protein content respectively 42.88% and 42.13%. Pravaker. P [52] Investigated Three sun-dried marine species' quality and safety. The quality of these dried fishes was based on organoleptic, biochemical and bacteriological study. The proximate composition analysis of Stromateus chinensis, Harpodonnehereus and Trichiuru shaumela showed Three different foods had high protein content: 60.03%, 41.28%, and 54.36% the lipid content was 11.92%, 10.48%, 11.45% respectively. Rahman and Mansur [53] a study on three dried in the sun fresh water fish's quality and safety. Quality of dried fish depends on the proximate composition of dried fish and safety aspects depend on the chemical and microbial contents of dried fish flesh. The three fresh water species Labeorohita, Channa striatus and Wallago attu showed protein content 59.32%, 62.85%, and 49.23% respectively. The quality assessment of improved sun-dried Trichiurushaumela by salt and turmeric powder treatment. Moisture, protein, lipid and ash content were measured as 17.16%, 50.95%, 4.97% and 12.74% respectively. In those studies, both marine water and freshwater dried fishes showed high amount protein, which indicates dried fishes are highly nutritious fishery product [54].

1.6 SPECIFIC OBJECTIVES AND POSSIBLE OUTCOME

Specific Objectives:

Specific objectives of this research are

1.Design and implementing Microwave Solar Drying System.

2. Experimental analysis of microwave solar drying fish.

3. Investigate the performance of the Microwave solar drying system.

4. Cost &benefits analysis to determine payback period of this technology.

Possible Outcomes:

1. Microwave solar drying strategy has the potential to significantly reduce drying time and energy usage.
2. Providing lower-cost, more nutritious foods to consumers will improve the Bangladeshi seafood sector's economic performance as well as environmental sustainability.

1.7 THESIS OUTLINE

Chapter-1: The introduction chapter, contains research background, solar energy in Bangladesh, importance of fish drying and objective for the study

Chapter-2: Reviews background literature relating nutritional value of sea fish, fish processing and preservation, fish drying, microwave solar drying, Solar microwave connective dryer.

Chapter-3: Systematically organizes the methodological framework followed in the study. Experimental design and fabrication, and proximate analysis and quality of dried fish included in this chapter.

Chapter -4: Includes performance analysis and comparative study include in this chapter and includes the cost analysis for Microwave Solar Drying System

Chapter -5 The summery of the research and discussion for future study in this field and recommendations for future scope of further study in this field.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLAR ENERGY SCENARIO

Solar energy is an endless source of pure, green, and ecologically friendly energy that doesn't harm either plants or animals [55]. The sun serves as the primary energy source in our solar system thanks to the all-powerful creator. The sun provides around 99.99% of the world's energy, while the earth contributes only 0.01% [56] and receives 89 PW from the sun [57]. About 3.8 1023 kW of energy are emitted by the sun every second. A little over 60% (1.08 1014 kW) of this volume is reflected back into space, leaving the other 40%. If just 0.1% of this energy could be converted with 10% efficiency, it could provide four times more energy than the world currently consumes. [58]. It is approximated that the sun could produce approximately 450 EJ of energy, which is equivalent to 7500 times the current global energy demand. [59].

The sun produces energy for free and with less labor requirement than other traditional renewables, making solar energy one of the most affordable and high potential RE sources today [60]. Solar photovoltaic technology is becoming more and more popular as a viable alternative for generating electricity. It is clear that by 2020, the world's combined on-grid and off-grid solar PV capacity would have reached 760 GW, up from just 23 GW in 2009, just 11 years earlier. Globally, solar PV capacity increased by about 115 GW in 2020. The largest capacity came from China alone at 35% (48.2 GW), while the United States contributed 14% (19.2 GW) of solar energy. In terms of overall additions, Japan came in third with about 6% (8.2 GW), followed by Germany with 4% (4.9 MW), India with 3% (4.4 GW), Australia with 3% (4.1 GW), Korea with 3% (4.1 GW), Brazil with 2% (3.1 GW), and the Netherlands with 2%. (3.0 GW). The remainder of the world's nations added about 21%. (28.7 GW) [61].

In Bangladesh, one of those in five persons are considered to be below the poverty threshold [62], compared to almost one in four in 2016 [63], which is only four years earlier. As the majority of these people reside in rural places and there aren't many of them anywhere, it's difficult to supply them with grid electricity. Gob has set a goal to supply electricity to everyone by 2020 and is urging people to accept solar energy as a result [64]. Due to the ease with which solar photovoltaic (PV) systems can deliver electricity to homes and small businesses, people in rural off-grid areas have enthusiastically embraced them. The advantages of solar energy are now available to all grid-connected and business or industrial consumers, as well as to rural off-grid consumers. They can use solar energy thanks to the installation of various solar cell types on their own property or roofs, which allows them to fulfill their own need and even sell any extra electricity to national grids. Due to solar energy, almost 20 million individuals in rural areas may now access electricity at night for work, education, and running small companies [65].

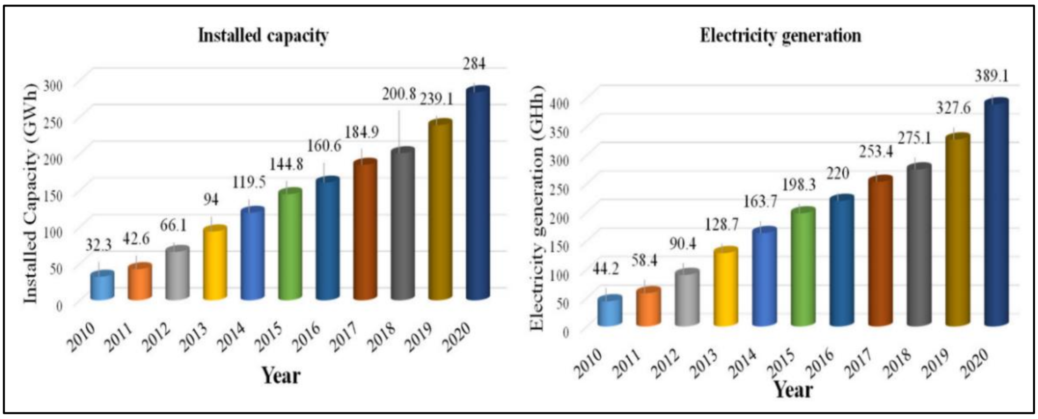

Figure 2.1: Bangladesh's Historical Solar Installed Capacity and Electric Generation [66].

Bangladesh achieved incredible achievement in the renewable energy field in 2017, moving up to the top 6 countries by renewable energy power and securing second place alongside Mongolia by utilizing 8% of electricity from off-grid solar energy systems. Nepal remained in the top place [61].

Bangladesh, a tropical to subtropical nation in Southeast Asia, is a single state with low-lying plain territory (apart from the hilly southeast), is primarily riverine, and is highly inhabited [67]. It spans the latitudes of 20°34′ to 26°38′ N and the longitudes of 88°01′ to 92°41′ E [69]. The country is 147,570 sq km [70] (56,977 sq miles) in size and is surrounded by Myanmar to the southeast, the Bay of Bengal to the south [71], and India to the east, north, and west. Bangladesh benefits from a sizable amount of sunshine, and solar energy utilization is growing there as solar equipment costs are falling [72].

Because of its geographic location, Bangladesh has abundant sunlight for the majority of the year [73]. Figure 2.2 shows the average monthly bright sunlight hour and average cloud coverage for eight divisional districts in Bangladesh from 2014 to 2018. Extreme sun emission occurs from March to April, and the lowest radiation levels are felt from December to January [74]. With the exception of clouds, rain, and fog, the amount of energy available is substantial, ranging from 4.0 to 6.5 kWh/m^2/day, and the sunny daylight hours vary from 6 to 9 h/day, or almost 300 days annually. This is sufficient to meet the sunshine need for solar energy [75].

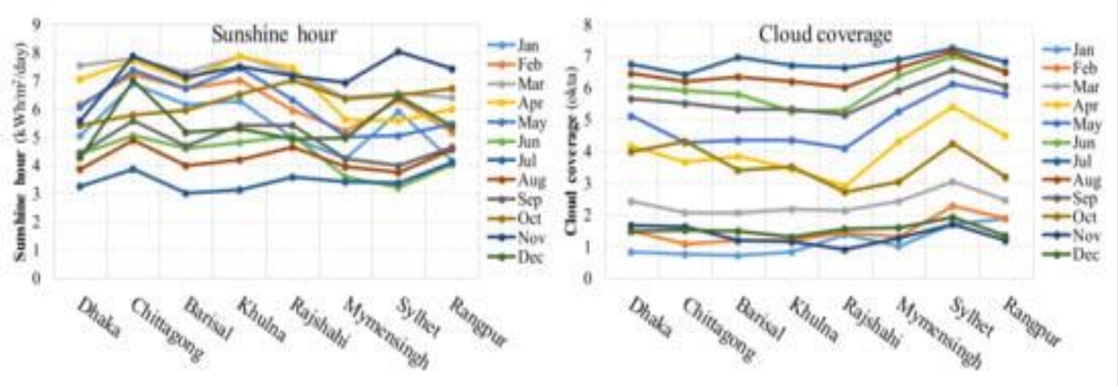

Figure 2.2: Average Bright Sunlight Hour and Cloudy Weather in Bangladesh's Eight Divisions (2014–2018) [76].

2.2 DRYING TECHNIQUES AND FISH DRYING

The elimination of water due to mass and heat transfer is known as drying that occurs under controlled conditions to decrease the size of the fish. [77,78]. Drying is a high-energy, high-heat process used in the fisheries sector to increase valuable and preserve the fish. As a result, By optimizing the drying processes, high-quality dried fish can be obtained by lowering energy use to increase drying effectiveness levels by lowering drying costs will also enhance the goal of drying fish [79-81] Recent times, design of a system, thermal energy analyses and optimization and efficiency have been done using energy analyses, which involve the greatest number of tasks that a system can produce [82, 83]. In the fish industry, convective hot air drying continues to be a widely used technique. for removing moisture from fish. However, this is fraught with a great deal of energy use, long drying periods, inefficient use of energy, contamination issues, and high costs, all of which hamper drying process effectiveness and efficiency and are unacceptable in the processing of fish [84, 85]. Utilizing modern techniques including such microwave as well as dielectric heating methods, on the other hand, will decrease ineffectiveness in the process and make it better thermal process effectiveness [86, 87].

When compared to the technique of convective hot air drying, these modern drying techniques have several advantages, including a faster rate of drying, a less drying time, less consumption of energy, and better dried fish product quality [88-90]. There are two types of drying techniques. These are natural methods that use the sun's energy to decrease fish's moisture content. The main drawback of this method is weather dependent and has ineffective performance in operation [91]. Artificial drying methods, on the opposite hand, have a number of advantages over natural drying methods. For example, Artificial methods are more efficient and effective at removing moisture from products, which produces more durable finished products. This allows for more drying parameters with high precision such as drying air fluctuation, drying time, and temperature. These methods improve drying efficiency by utilizing mechanical or electrical equipment [92].

Direct drying is the process of using sunlight energy to dry fish. It is an old method of drying. Samples of fish have been set on the platform for drying in the sunlight. Depending on the size of the fish and the moisture content. The duration of drying can range from several hours to several days. Sun drying is popular in tropical and growing nations where people benefit from greater sunlight but lack the infrastructure necessary for the use of contemporary drying facilities. Furthermore, this method thrived due to the high cost and scarcity of fuel [92]. The following issues, however, arise when drying fish in the open air under the sun: pest and bug contamination of the products; dust and dirt; ineffective drying; ineffective process control; unsteady quality, and inefficient heat use as an effect of evaporating moisture condensing [93]. Little fish or fish fillets are now dried using a basic sun dryer, which increases drying efficiency and quality of products [94]. Fish and other agricultural goods have also been dried using direct-type dryers controlled by the sun [95].

To fix the disadvantage of the direct drying method, this entails the use of indirect sun dryers. Indirect solar dryers come in a variety of designs, including as chamber, chimney, and wind-ventilated dryers. In contrast to direct drying, the air that passes through to the item to be dried is heated by the heat that is as a result of the associated sun drying system. To get rid of evaporation-related moisture, the drying chamber's top is vented [96]. The absorber made of flat plates, glass with cover, wire mashing, chimneys, drying chambers, and absorption glass make up the composite absorber system of the indirect sun dryer. The afternoon drying air temperature climbs to 40°C when the apparatus has been warmed to dry samples of fish, which enhances the flat plate collector's thermal efficiency. A mathematical model was created utilizing the thin layer solar dryer for indirect forced convection that was used to dry strawberries could be used to dry fish [97].

Using heat from a heating source, the convective drying technique removes moisture from fish. The fish samples are exposed to hot air, and mechanical fans can be utilized to increase heat circulation and dry the fish effectively [98]. Using the appropriate airflow rate and a temperature range of 50 to 90 °C, hot air tunnel dryers have been used to dry a variety product of agricultural. These dryers could also be used to dry fish. The research also revealed a decrease in anthocyanin concentration and antioxidant power in dried strawberries produced by convective drying [99]. Traditional convection hot air drying has been observed to lose heat-sensitive fish and dried fish product components due to long drying times and high temperatures. Radiation drying is the use of electromagnetic waves to achieve drying at a specific frequency and wave length. Drying is accomplished with a lower temperature and less time. This has been utilized to address the drawbacks of conventional convective hot air-drying methods [100]. The main drawback of using a microwave or radiation drying is scorching. The ability to combine microwave drying with other drying techniques, such as vacuum drying, is its main advantage, though [101]. The button mushroom was dried using a microwave-vacuum drying technology, which may also be used to dry seafood. When compared to the convective method of hot air drying, drying of microwave was found to have a quicker drying time, improved product quality, and rehydrating capabilities [102]. Food has been dried using other radiation-based processes, such as infrared heating [103]. Moreover, the infrared drying approach has been used to dry a variety of vegetables, including tomatoes, carrots, and sweet potatoes [104, 105,106].

This method dries items by directly sublimating moisture through direct sublimation and freezing. Drying is carried out using the freeze-drying method at a significantly lower temperature. The eradication of the majority of microorganisms is also accomplished when liquid water is not present during freezing and low temperatures are used for drying, according to research by [107]. Also, they discovered that the initial stage of freezing and drying removes the majority of fish's moisture. Products that have been freeze-dried have the ability to rehydrate and regain qualities identical to the original products [108–110]. Moreover, freeze-dried goods have a quick rehydration NFS 49,5 890 ability, and their rehydrated organoleptic qualities are nearly identical to those of fresh goods. The freeze-drying method has the following benefits: minimal volume loss, minimal change of chemical, minimal volatile component loss, long storage period, as well as stability [108]. The drawbacks of the freeze-drying procedure, however, include energy and cost needs, a lengthy freeze-drying process that may cause the product to collapse, lose its aroma, become rough, and have poor rehydration properties [109, 110]. of the rehydrated goods is virtually identical to that of the fresh goods.

2.3 DRYING KINETICS AND MODELLING

Drying the kinetics is a theory has recently attracted attention in relation to food drying. It explains the microscopic and macro mechanics of to occur is the transfer of mass and heat when food is dried. It has been discovered that a number of variables, including drying circumstances, drier types, and the properties of the materials to be dried, have an impact on drying kinetics. The study kinetics of drying has given researchers many options for choosing the best drying methods and for managing the drying processes. Moreover, both process and engineering improvement have exploited drying kinetics. The development of a drying model requires an awareness of the kinetics of drying, which explains how moisture is separated. as it interacts to process variables [111]. Various drying models with thin layers, and models have already been described by [112] empirical, semi-empirical, and theoretical. Every model was created using a set of fundamental assumptions. Whereas semi-theoretical and empirical methods take into account external barrier to moisture absorption between air or products, theoretical models only account for internal moisture transfer resistance [113]. Nevertheless, empirical models just explain the drying curves for the situation of drying and overlook the processes that occur during drying while overlooking drying concepts [114]. The Lewis model, the Logarithmic model, and the Page model are a few examples of semi-theoretical drying models. The popular theoretical model includes, as an example, Fick's second diffusion law. Theoretical models have a number of drawbacks, including the fact that they produce inaccurate conclusions and are too sophisticated for use in real-world situations. In order to better the fillets of fish that will be drier’s drying data fit, semi-theoretical models for food drying have been devised [115–117]. Although Handerson and Pabismodel has been used to simulate the drying of maize, the model was unable to fit during the first 1–2 hours of drying because of accuracy and a significant temperature differential between the air and corn seeds [118, 119]. has submitted The Handerson and Pabis model is a specific case of the Lewis model. However, it has been discovered that the model is erroneous since it overestimated the first period of drying and underestimated the last period. Yet, simplified solutions of general series of the second rule of Fick's semi-theoretical models are. They only work properly when the range within which the models are built for moisture, air velocity, temperature, and humidity is met. Time requirements and the morphologies of the materials to be dried are not included in semi-theoretical models [118, 119].

It has been discovered that air temperature has significant impact on the drying kinetics of food. The drying characteristic, equilibrium moisture level, and moisture diffusivity have been found to have a connection between drying temperature. Many research has been done on how air temperature affects the kinetics of drying [120]. To describe the kinetics of drying, three empirical models were used: the Page, Logarithmic, and Henderson and Pabis models [121]. The drying of tomato slices at various air temperatures revealed inconsistent drying at high temperatures, highlighting the significance of diffusion as a key physical process for removing moisture. In a different investigation, It was discovered that the initial-order drying kinetics accurately predicted the drying kinetics of the specimens at two various temperatures — elevated and—regardless of the sample size and the air conditions. Also, it was found that there was an inverse link between the moisture equilibrium of the samples and the temperature of the air [120]. The temperature goes up and drying air velocities have been seen to affect drying time. They also noted drying time as well as air velocity have an inverse relationship and temperature [122].

Borges, S.V., has investigated how form affects drying kinetics [123]. Produce cut into disk and cylindrical forms were dried in a tray dryer, and The rate of drying was discovered to be for disk-shaped produce was significantly higher than for product in cylinder shape. Alivlotlso noted that temperature had a favorable impact on the produce and that blanching had a noticeable impact. Also, it was determined that air temperature and air velocity had a significant impact on the drying time. The quality of the food and the drying procedures are improved through pre-treatments. Produce is treated with it before drying. in order to reduce drying time, improve flavor, maintain nutritional value, and preserve taste. Pre-treatment speeds up the drying process by lowering the initial moisture content and altering the produce's tissue [124]. Pre-treatments such blanching, filleting, sulphuring, salt solution or osmotic pre-treatment, NaOH, and skin removal are widely employed on products before drying operations [125–127]. Due to its advantages, pre-treating fish before drying is crucial. Pre-treating expedites fish drying and lessens the negative impacts of drying operation on several fish quality measures. It also assists in the preservation of color of dried fish and prevents darkening during drying and storage [128, 129]. While drying produce, dangerous bacteria including Escherichia coli O157:H7, Salmonella spp., and Listeria monocytogenes are also eliminated by pre-treating the produce with an acidic solution or sodium metabisulfite dip [130].

The quantity of air moisture that exists at a specific time is known as the relative humidity. It has a significant impact on the drying kinetics and pace of fish fillets. The impact of the effects of humidity and temperature on the kinetics of produce drying has been investigated by numerous researchers. We employed various drying temperatures and RH (Relative humidity) levels while maintaining a consistent air of velocity. They discovered that compared to the other models employed in the experiment, a two-term model better described the drying kinetics. Moreover, they noticed that, under constant air humidity, drying time had an inverse relationship with temperature. Also, the initial water content of a produce meant that the air's relative humidity had no impact on the drying curve. [131].

The level of relative humidity is the quantity of moisture in the air at a given point in time. It significantly affects the rate and dynamics of fish fillet drying. Several studies have looked into how humidity and temperature affect the kinetics of crop drying. Using air velocity that is constant, we used a range of temperature levels and relative humidity levels. They found that a two-term model better captured the drying kinetics than the other models used in the experiment. Moreover, they discovered that drying time had to have an inverse correlation with temperature when the air humidity was constant. Because of the initial moistness of a product, the drying curve was not impacted by the relative humidity of the air [132].

The amount of air that is moist at any one time is measured by the relative humidity. The rate and kinetics of fish fillet drying are considerably impacted. How humidity and temperature impact crop drying kinetics has been the subject of numerous studies. We employed a range of temperatures and humidity levels with a constant air velocity. They discovered that compared to the other models employed in the experiment, a 2 model better described the drying kinetics. Also, they found that while the relative humidity was constant, drying time must have an inverse relationship with temperature. The initial water content of an item also indicated that the air's relative humidity had no bearing on the drying curve.

2.4 FISH PRESERVATION AND MICROWAVE SOLAR DRYING

After harvesting, proper processing and preservation are very important for extending the shelf life of fish, Processing reduces the actions of microorganisms and their proliferation which prevents microbial spoilage and extend shelf life. Preservation and designed to inhibit the bacterial spoilage and metabolic changes, which are the causes of quality loss in the fish. A series of complex enzymatic, bacterial and chemical changes take place in fish body which indicate fish spoilage and its beings after harvesting of fish [134]. To prevent spoilage there is a range of processing methods can be used which divided into two groups- modern fish preservation method and traditional fish preservation method. Modern fish processing methods included freezing, chilling, canning, marinating etc. Salting, drying, smoking, fermentation are the traditional methods of fish preservation.

During processing fish, drying is primarily used to ensure the material is stored safely and to stop microbial growth. Drying often refers to the process of moisture evaporation brought on by simultaneous mass and heat transfer [135]. When the surface has free moisture, a steady drying rate is seen throughout the initial drying stage. This stage sees the evaporation of this liberated moisture [136]. The area exposed to the dry air, the difference in temperature between the wet surface and the dry air, and also the external mass and heat transfer coefficients [137] all have an impact on the rate of drying at this stage, which is surface-based. Following this time, the moisture must be distributed from the interior of the material to the surface to aid in dying. Thus, the drying rate transitions from the consistent rate stage to the first falling stage beyond the point known as the critical moisture content (MCc). The drying rate during this stage is primarily influenced by tissue thickness, shape, and collapse. Because of the absence of moisture at the surface, heat damage may happen at this point. Because to the increased internal resistance to moisture transfer and the decreased heat flux during the first falling-rate stage, the drying rate declines even as moisture content rises. The diffusion that results from the concentration differential between both the core region as well as the surface causes moisture to flow from of the centre to the surface during the second falling rate. Due to shrinkage and a reduced moisture gradient, the diffusion rate drops during falling rate drying phase, extending the drying time. The drying rate during this later decreasing rate period is significantly too sluggish; according to the literature, it takes almost as long to remove the final 10% of water off food products as it does to remove the first 90%. Most food products and some biological materials exhibit drying behavior during this second stage of dropping rate. This step of drying is accelerated by supplying additional energy by raising the temperature of the drying air. Although the product's moisture content is still high in the center, high temperatures can harm the product's surface and cause a hard crust to form [138]. Food materials are poor heat conductor, which restricts the amount of heat that can be transferred from of the surface to the interior. Hence, the surface overheats and becomes damaged. The heat and mass transmission rates are ultimately slowed by this damaged surface, which prevents future drying. 1991 I.W. Turner [139] The main drawbacks of the use of hot air include the development of crust, increased drying time, and inferior food quality. A cutting-edge drying method like the microwave sun dryer can be used to address these issues.

Microwaves are electromagnetic waves with wave lengths between 1 mm and 1 nm and frequencies between 300 MHz and 300 GHz. This is the space-based transmission of electromagnetic energy using dynamic magnetic and electric fields [138]. Once moisture is found, microwaves penetrate the material to heat it up volumetrically and pinpoint the moisture, which allows for a higher rate of diffusion and differential pressure to force the material away [139]. Bipolar re-orientation and ionic state are the two major mechanisms of microwave heating. Due to their bipolar nature, water molecules attempt to follow the rapidly alternating electric field. The electric field shifts direction 2.45 billion times per second at a typical microwave frequency of 2.45 GHz, which causes the dipoles to move with it [140]. Inside the food material, such molecular spinning causes friction and heat to be produced [141]. Ions, like those found in salty food, migrate under the influence of the electric field, resulting in the ionic state, which is the second main mechanism of microwave heating. The use of microwaves in combination with other drying techniques can greatly speed up drying due to its capacity for volumetric heating. The main benefits of drying with a microwave are. The interaction of microwave energy with the water molecules in the food causes volumetric heating and faster moisture diffusion rates [142]. The drying time might be greatly decreased as a result [143, 144]. The research makes it abundantly evident that microwave convection drying (MWC) results in a noticeably shorter drying than convective drying (CD) [142, 145]. By adjusting the pulse ratio and power level of the microwave, it is possible to regulate the fidelity of heating utilizing this radiation [146]. Using microwave heating, wetter areas can be heated preferentially, and microwaves can even excite bound water molecules [142, 146]. Uneven heating and overheating of food materials are caused by continuous MW energy supply due to unequal MW power distribution. The sporadic introduction of MW energy can be a solution to this issue. The intended temperature of the food products during drying and the homogeneous distribution of moisture within the food materials are both maintained by this intermittent application of MW, which enhances product energy efficiency and quality [147]. Many researchers combined intermittent microwave energy with various drying methods, including vacuum drying [148] or freeze drying [149], and they discovered that dried samples had better quality characteristics than vacuum- and freeze-dried products. In addition to these, the literature has also reported on the benefits of PMSD in terms of quality and energy efficiency. Many products have been shown to benefit from PMSD in terms of increasing energy efficiency and quality of products as well as drastically cutting drying time. The summary on the research of PMSD has been extensively represented in Table1.1

Table1.1 Summery of research Regarding pulsed microwave solar dryer

Year	Material	Approach/ Methodology	Measured Properties	Limitations	Reference

2009	Sea Fish	Developing a microwave heating model with variable dielectric properties and governing equations	1.Effect of moisture content 2. Comparison between experimental and simulation results	1.Theotical modelling only 2.No Micro-controller unit 3.No proximate analysis was performed	[150]
2011	Tilipia Fish Fillets	The experiment was carried out in dryer which consist of a microwave generator within output 200W, 400, and 600W and 2450Hz. Moisture content was measured by weighing the digital Balance at regular intervals of 10 minutes.	1.Rehydration Ratio 2. Shrinkage Ratio	1. No solar assisted 2.Unable to measure moisture content 3.No proximate analysis was performed	[151]
2011	Shrimp	Microwave oven Finding the effectiveness of Various microwave-convective drying	1.Microwave drying kinetics 2. Energy efficiency of microwave drying	1. Unable to measure rehydration ratio 2. No Temperature Distribution	[152]

		treatments of Shrimp.		3. No proximate analysis was performed	
2012	Sardine fish	Microwave oven having four continuous output power setting of 200W,300W, 400W and 500W operating at 2.4GHz provided with wave guides was used as a dryer.	1.Drying Rate 2.Moisture Ratio	1. No solar Assisted 2.Unable to measure rehydration ratio 3. No Temperature Distribution 4.No proximate analysis was performed	[153]
2013	Bighead Carp	microwave drying (MD) and combined air-microwave drying (AMD) were studied during the initial period of 0–120 seconds.	1.Effect of power levels on MR	1.Not Energy Efficient. 2.No Temperature distribution 3.Not automated 4.No proximate analysis was performed	[154]
2013	Clip fish	Microwave (MW)	1.Drying kinetics 2. Moisture content.	1. Not Energy Efficient	[155]

		assisted convective drying of clipfish (cured cod) was investigated at different intensities		2. No Temperature distribution 3.No proximate analysis was performed	
2018	Rainbow trout	Three different infrared radiation power levels of 83, 104, and 125 W were used for infrared drying, while microwave power levels of 90, 180, 270, and 360 W were used for drying the samples.	1.Drying kinetics 2.Effect of Power Level on Drying Rate 3. Moisture Content	1. Not Solar assisted 2. Unable to measure rehydration ratio 3.No proximate analysis was performed	[156]
2022	Tuna chunk	Finding the effectiveness of various microwave-connective drying treatments of tuna chunk and comparing to typical sun drying.	1.Colour 2.Rehydration 3. Bacterial and mold growth	1. No microcontroller unit 2. Unable to measure moisture content 3. No Solar assisted. 4.No proximate analysis was performed	[157]
2022	Silver Belly	Comparative studies with the effect of hot-air	1.Drying rate 2. Moisture content	1. Unable to measure	[158]

		microwave heating and sun drying	3. Proximate composition analysis 4.Bacteriological aspect	rehydration ratio 4.No proximate analysis was performed	

Drying is a significant industrial process for food preservation that almost 20–25% of the energy utilized in the sectors that process food. However, there is a huge lack in the fields where research could be done on effective and energy efficient process of drying, and modifications of the present drying systems and many more. The pulsed microwave drying treatments are basically less energy intensive than the conventional dryer. In addition, the pulsed microwave–convective drying requires lowest drying time than all the other conventional drying treatments. But, compared to the other processes this system also consumes substantial amount of energy that finally put pressure on the national grid. To meet up this demand significant amount of power need to be produced that finally generate huge amount of emission. The use of renewable energy, such as solar energy, can therefore be a significant option for powering the dryer. To address this problem, an inventive pulsed microwave sun aided convective drier has been created in this study. From these conclusions, it's clear that a comprehensive PMSD setup dependent on the renewable energy sources for running purpose is necessary to reduce the dependency on national grid, and this is not available in the literature. Moreover, a simple system is also obvious that will require less floor area and dry the fish material samples in a quickest possible time by sustaining all the quality attributes in a maximum manner.To address this necessity, a microwave Sola dryer setup has designed and manufactured and all the necessary investigation has accomplished to evaluate the performance of the innovative Microwave Solar Dryer setup.

CHAPTER 3
MATRERIALS AND METHODOLOGY

3.1 METHODOLOGY OF THE RESEARCH WORK

One of the most significant techniques in fish processing is fish preservation through heating. Drying is the process of making a product dehydrated by evaporating free water using heat. Microwave energy drying is an alternative drying method that offers advantages like excellent conduction of heat to cleaning the inside of a dried material, energy recovery, energy process management, and quick start and stop of the drying process**.** The flow chart of methodology is given in Figure 3.1.

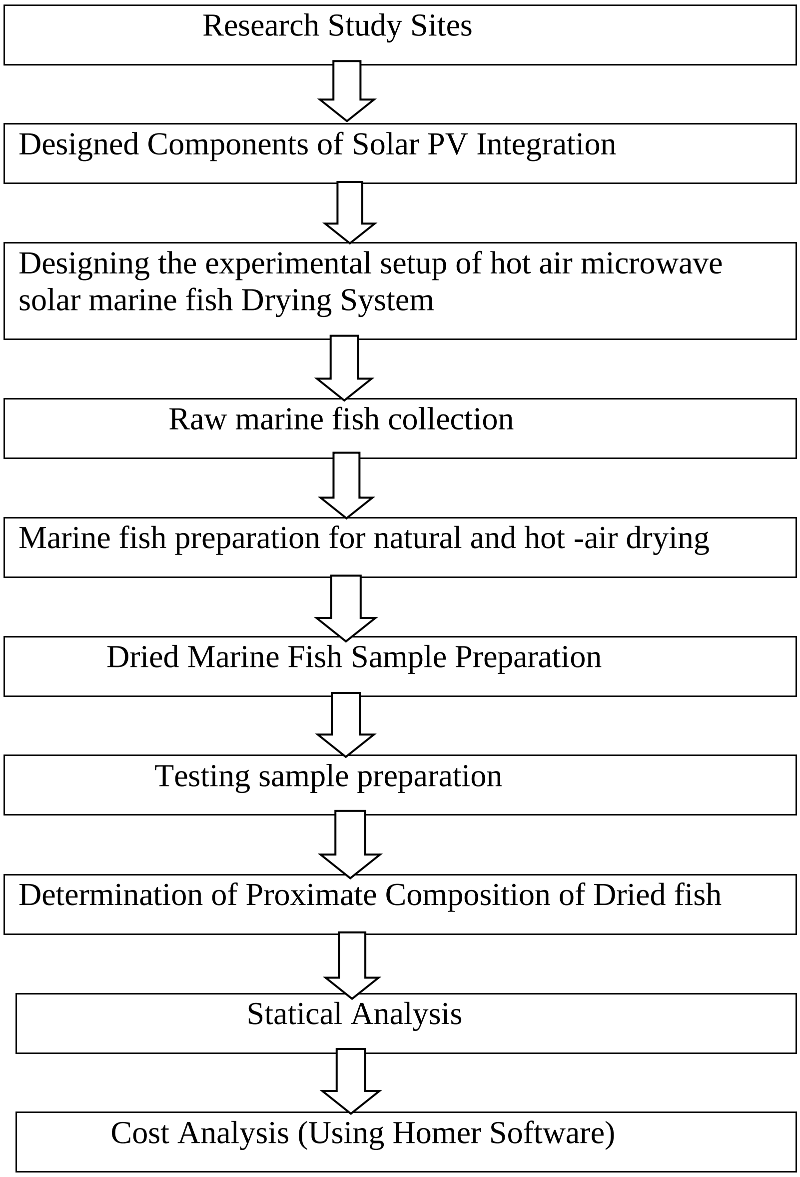

Figure 3.1: Flow Chart of Methodology of the Research Work

Figure 1.3 shows the total work process of this research. 3.1.1 research study site and marine fish sample collection discussed about the research site selection, operation of fish drying and test of the quality of dried fish. 3.1.2 designed components of solar PV integration explained about the site selection for the PV module installation and energy consumption calculation for drying system.3.1.3 main components of the marine fish drying experimental setup were discussed. 3.1.4 discussed about methodology of the marine fish drying (traditional and hot-air microwave) process and also microwave drying working process of the setup is explained. After drying the fish, it was ready for sample preparation and determination of proximate composition of dried fish was discussed in 3.1.5. Statical analysis (3.2) to determine the variability of data in different observation, standard deviation (SD) is calculated. Cost analysis using by Homer softer is discussed 3.3 and show the cash back theory to describe the cost efficiency.

3.1.1 Research Study Sites and Marine Fish Sample Collection

This experimental research study was performed in improved microwave marine fish dryer at the Institute of Energy Technology Laboratory, Chittagong University of Engineering & Technology. Nutritional and microbial test study was conducted in Poultry Research and Training Centre, Chittagong Veterinary and Animal Sciences University. In this experimental study, the marine fish such as silver belly (Leiognathus Bindus), Bombay duck (Harpodonnehereus), Silver Jewfish (Otolithoides argenteus) which are locally known as Tek Chanda, Loittya, and Poa fish respectively were drying. The marine raw fish samples were collected from Fishery Ghat, Chittagong. For comparative studies, some dried fish samples (Ribbon Fish (Trichiurus haumela), Bombay Duck (Harpodon nehereus), and Silver Jew fish (Otolithoides argenteus) were collected from Cox’s Bazar and Saint Martine and also similar sample fish are dried naturally the fish sample naturally in CUET campus.

3.1.2 Designed Components of Solar PV Integration Drying System

Solar Photovoltaic Integration:

Solar panels, also known as photovoltaic modules, are a web that absorbs and converts solar radiation into renewable energy. Each solar cell is constructed from a semiconductor material, most commonly silicon. Because of these natural occurrences, it is photovoltaic effect sensitive and generates electricity when exposed to sunshine. A utility-connected PV system has the following elements.

1) PV panels that are attached to an inverter.
2) The inverter, which changes the direct-current (DC) electricity used by the system into alternating current (AC)
3) The charge controller (MPPT) which is used for controlling the charge of the battery bank.
4) Batteries to provide energy storage and supply the power to experimental setup.

Site Selection for the PV module installation:

A well-designed PV module needs clear and unobstructed access to the sun's rays for most or all of the day, throughout the year.

Figure 3.2: PV Module (800 Wp) on Rooftop of Academic-2 (EME) Building, CUET.

We have done an initial assessment for site selection to install the PV module of power 2KWp. Bangladesh is very close to 23.5^0 North of the equatorial line. It has benefits in two different ways, the variation of the length of the day from winter to summer season is smaller than in most of the other countries. And another advantage is sunlight falls perpendicularly on our land for a longer period throughout the year. CUET also cover Latitude: 22.45^0 Longitude 91.97^0. We have selected the site of the roof top of three stored Academic building-2 (EME Building) of CUET. Figure 3.2 shows the installed Solar PV module(800Wp) for maximum sunshine in a day from 10.00 Am to 4.00 PM.

Energy Consumption Calculation for Drying System:

Hot air dryer power consumption is 500 watt per hour. It was run for 5 hours.

After completed the hot air-drying process. Then the raw materials put into microwave oven for 30 minutes maximum.

Microwave oven power consumption is 500 watt per hour.

So, total consumption of electrical energy = 500 watt for 5.30 hour

Electrical energy consumption by hot air dryer and microwave oven

= E (KWh)=P (W)×T(hr)/1000

Electrical Energy needed in a day (5.30 hours) for experimental setup

E= 500 × 5.30/1000= 2.65Kwh

Solar PV Module Selection:

Step 1: Calculated the daily energy consumed by the load in watt hours.

Daily power consumed

= Hot -air and Microwave dryer wattage × Daily operating hours (Wh/day)

Step 2: PV power produced

= Daily Power Consumed / (Load Efficiency × Battery Charge/ Discharge Efficiency)

Step 3: Watt of the PV panels = Hot -air Microwave dryer wattage / PV panel load efficiency

Solar assisted microwave solar dryer and hot air dryer needed per day (10 AM to 4PM) for 6 hours was 2.65KWh.

By considering 60-65% PV panel load the required panel size.

Total watt of the PV panels/ hr.= 2650 KWh/ 0.6×6 = 736 watt/hr.

So, we need ≈ 800 watt/hr.

Consider 200 watts 1 panel

Total panels required =800watts/ 200watts = 4 Nos (200 watts)

Inverter Capacity (VA) calculation:

VA requirement = Power requirement x power factor

Assume power factor as 0.8 for safe. For Microwave solar dryer and Hot air dryer (500 watt + 500 watt) 1000Watt of power is required. Therefore, our inverter must support 1000 watt of power requirement.

Considering power factor 0.8, the inverter VA requirement shall be

=1000/0.8 =1250VA

Due to some loss so, we consider 1500VA Inverter.

Storage Battery and Battery Bank Capacity:

Inverter selection is done for the peak load, while battery is selected for duration of power requirement.

Size of battery = (Load requirement x Backup Hours) / Voltage

Where, Load requirement =Power load for inverter backup,

Backup hour = Total hours backup in needed

Voltage = Voltage of battery

Considering backup 5.30 Hours and battery voltage of 2×12V=24Volts,

Size of battery required shall be = (2650)/24 = 110Ah

So, we need two sizes of battery with 40 Ah loss consider

the Battery rating should be (110Ah +40 Ah) = 150Ah

Depth of discharge DoD: The depth of discharge of a charged 150 Ah battery is discharged for 320 min at constant current 2.5A is calculated by

$$= \frac{2.5\times\frac{320}{60}}{150}\times 100$$

$$= 8.88\%$$

3.1.3 Main Components of the Marine Fish Drying Experimental Setup:

a) Solar panels: are made up of individual solar cells that are joined to create solar modules, and several solar modules are connected to create a solar array. For best power output, the solar panels can be connected in a series parallel, or series parallel configuration.

b) Charge Controllers: Charge controllers are used to prevent battery overcharging by attempting to prevent high voltage that damages batteries. The most basic charge controller for the home employs a technology known as Pulse Width Modulation (PWM), whereas the best charge controllers employ Maximum Power Point Tracking (MPPT).

c) Batteries: Deep Cycle Batteries are required for electricity storage, but more specialized batteries, such as Tubular Batteries, are gaining popularity for larger applications. For running the project, we used 150 Ah battery.

d) Power Inverters: Direct Current 24V electricity generated by the PV panel is transformed to Alternating Current (AC). To prevent excessive current from flowing to the battery in the event of a short circuit, a circuit breaker must be placed between both the charge controller and the battery storage system before the DC load may be connected to either device. Which can be replicated at all the necessary points and used inverter is 1500VA.

e) Microwave oven: A microwave oven typically consists of a High Voltage Converter because, unlike many other home appliances, it uses more power than what the electrical wiring in a typical home can supply. A step-up transformer with a high-voltage output is put inside the oven to achieve this. The cavity magnetron receives power from the 240V source after being jumped to a few thousand volts., which is then fed to the cavity magnetron. Microwave frequency is 2450 MHZ, output 1000 watts.

f) Hot air oven: Hot air oven consists of a fan, a heat source, a drying chamber, and trays can uniformly dry fish. This oven automated controlled 50^{0}C with a constant air speed of 1.5 m/s and its output wattages 500 watts.

3.1.4 Methodology of the Total Marine Fish Drying Process:

Methodology of the total work process is given in Figure 3.3. After collecting marine fish, it was finely dressed and gutting was carried out properly followed by washed with potable water.

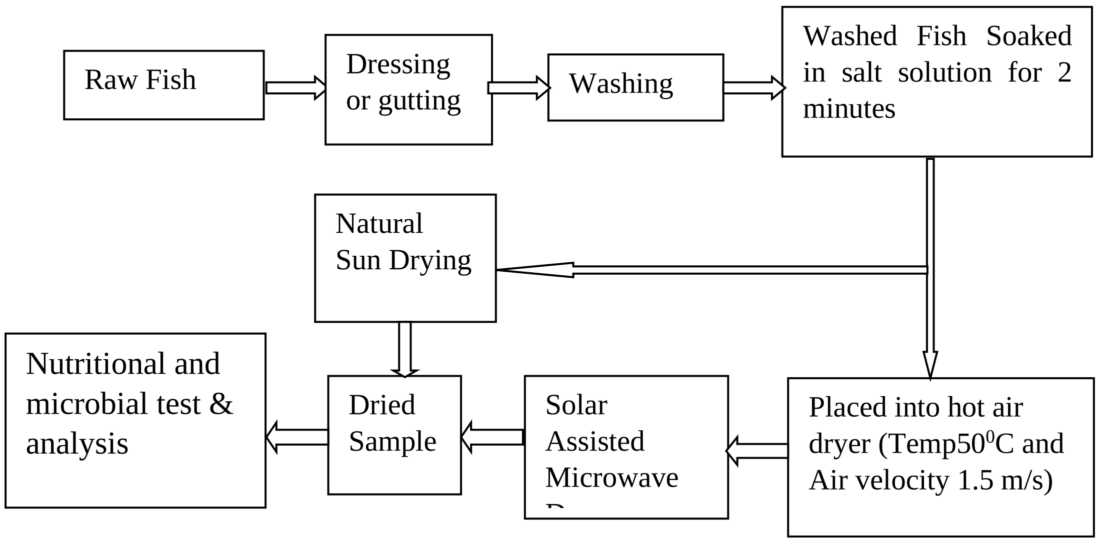

Figure 3.3: Block Diagram of Marine Fish Drying Process.

Then properly sample washed fish was soaked in salt (5% of the sample weight) for 2 minutes (Figure 3.4). The prepared fish sample was then for hot air microwave drying.

(a) (b)

Figure 3.4 Bombay Duck Fish (a)Washed Fish Sample (b) Fish Soaked in Salt.

At the same time similar sample after final washing was placed in the open sun for natural drying. The dried fish samples then tested for nutritional and microbial & analysis.

3.1.5 Traditional Natural Sun Drying of Marine Sample Fish:

Removing the fish's body's water content is part of drying. This method is carried out in sun drying by placing the target fish straight in the sun. The fish's water content is often evaporated in the open utilizing solar energy. The water that evaporated from the fish body was removed by natural air. So, the Sun drying process was performed at top floor of the Academic building-3, CUET**.** Figure 3.5 shows the traditional fish drying process (a) Bombay Duck (b) Silver Belly Fish.

The raw fish directly hanged on rope under direct sunlight without covering. The samples were kept in the sun and weighed every half hour interval from 10.00 am to 4.00 pm. During the night the fish were well covered to avoided entering moisture from surrounding. When the moisture content decreased to less than 0.1 than it was considered as dried fish. Finally, the samples were ready for proximate composition and microbial quality test.

(a) (b)

Figure 3.5: Traditional Fish Drying Process (a) Bombay Duck (b) Silver Belly Fish in CUET

3.1.6 Hot Air Microwave Drying Marine Sample Fish.

A hot air-drying oven that primarily consists of a fan, a heat source, a drying chamber, and trays for uniformly dry fish. The air is directed to a heat source during drying,

(a) (b)

Figure 3.6: (a) Hot Air Dryer and (b)Pre-dehydrated Fish

The fish sample were placed in the automated hot air dryer and drying was carried out under controlled temperature at 50^0C and a constant air velocity of 1.5 m/s, the sample marine fish was pre-dried for 5 hours. The sample fish was not overheated or underheated due to an automatic temperature control system. Figure 3.5 shows the (a) Hot Air Dryer and (b) Pre-dehydrated Fish

3.1.7 Solar PV Microwave Marine Fish Drying:

The experimental microwave drying set-up is given in Figure 3.7 which consists of three main parts of the waveguide, cavity, and air duct. The waveguide is used to transfer microwave power from the magnetron probe into the cavity. It is a rectangular hollow tube which is made of stainless steel. One end side of the waveguide is mounted with a magnetron and the other end, the cavity part is a rectangular hollow conductor wall that is made of stainless steel. The cavity has a rotating plate that is rotated at 5 rpm on a ball-bearing shaft driven by an electrical motor. The dimensions of the microwave cavity are (305mm×204mm×356mm). The spinning disc was required to achieve relatively homogenous drying and to reduce the level of reflected microwave ovens onto the magnetrons. On the left side of the oven, there are ventilation holes. Another part of the experimental setup is the air duct that is attached to the outer surface of the microwave oven. The air duct (12 inch long and 4.5inch diameter) is used to measure the speed of the air inside the oven. The air flowing through the air duct is blown through a hole in the orifice meter inside the duct. The Pitot tube is attached to the hole in the center of the orifice meter. Manometric height is found on a millimeter scale on the manometer attached to the pitot tube to reduce the supply of external power, the entire power supply was carried out with a solar panel as a power source. A charge controller 50/100 Ah used for charging the battery. Battery (12V, 150Ah) is used which will be charged with solar panel and inverter converts the DC into AC. The system was designed to be capable of employing diverse drying processes such as continuous microwave convection and convective air drying. The pre-dehydrated sample fish have been dried in the microwave right away. 80% or more of a fresh fish is water. It is a perishable material with a short shelf life. As a result, research into the process of drying of fish is required. The impact of microwave drying on the rate of drying, effective diffusion, and consumption of energy of Bombay duck, silver Jew, and silver belly fish was investigated in this study at two different power levels: 200 watts and 400 watts. As a result, the microwave heating systems paired with circulation of hot air for right away elimination of moisture from the product and significantly reduced drying times in the drying process. The moisture level of all three different drying fish was reduced to 0.1 with a 6-minute reduction in drying time due to an increase in microwave power. The effect of hot air and microwave drying on the dietary needs of marine fishes was studied, and their value revealed an excellent level of proximate composition. When compared to conventional fuel/electric dryers, solar assisted dryers are more cost effective in terms of operation and maintenance. The process of drying is carried out in the most hygienic and environmentally friendly way possible.

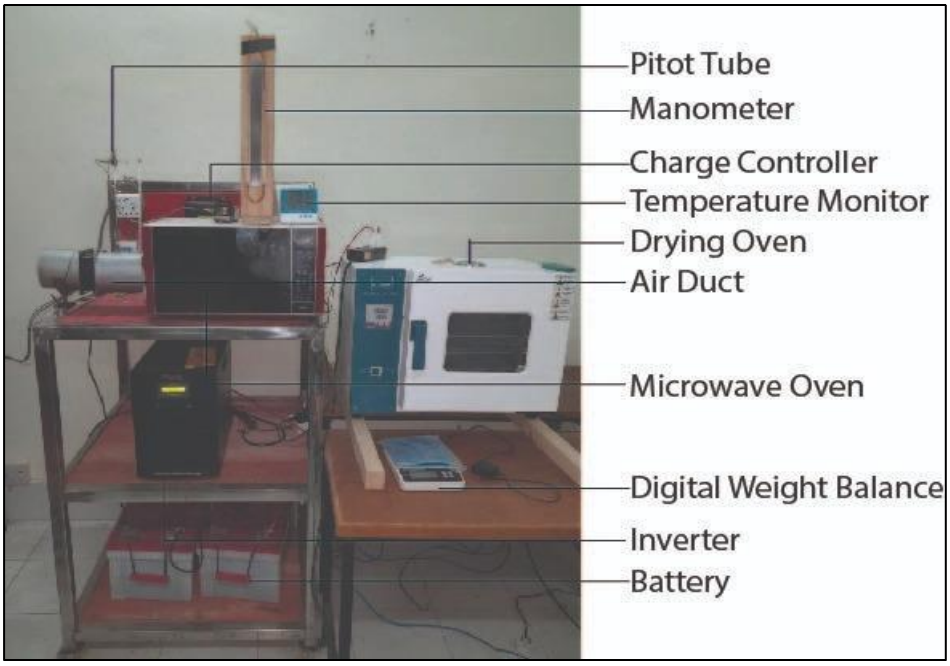

Figure 3.7: Experimental Setup of Hot Air and Microwave Solar Marine Fish Drying System

Microwaves are used in the drying process to penetrate the moist material, where they are transformed into heat. The moisture turns into vapor and is transported from the oven through an exhaust fan. The pre-dehydrated sample fish were dried in microwave dryer for 400watt and 200watt power different air velocity 0.10m/s, 0.11 m/s, and, 0.12 m/s. Figure 3.8 shows the microwave dried fish of Bombay duck and Silver Jew fish (200 watt and 0.10 m/s)**.**

(a) **(b)**

Figure 3.8: Microwave Dried (a) Bombay Duck and (b) Silver Jew Fish

During the experiment in two different watts, different temperatures were observed in the microwave oven. Which is measured with a digital temperature monitor. Appendix A1-A3 as can be seen.

3.1.8 Determination of Proximate Composition of Dried Fish

Moisture, crude protein, crude fiber, crude fat, ash, calcium, and phosphorus of dried fish sample were analyzed according to AOAC (AOAC, 2016) methods.

Determination of Percentage (%) of Drip Loss:

After sampling, initial weight was measured by electronic balance in the sampling site. Then the sample was covered with ice an in-ice box and it was brought to the laboratory. It was weighed again in the laboratory. From differences of two weights, the percentage (%) of drip loss was measured. The difference in weight (g) was divided by the initial weight (g) of the product and expressed as g/g% [159]. Drip loss was calculated by using the following formula:

$$\text{Drip Loss (\%)} = \frac{\text{Initial Weight (g)} - \text{Weight after holding (g)}}{\text{Initial Weight (g)}} \times 100 \qquad (3.1)\ [159]$$

Determination of Percentage (%) Trimming Loss:

Firstly, fish was weighed before dressing to determine the trimming loss. For drying purpose fish was washed, gutted. After dressing, fish was washed again. Then dressed fish was weighed again. From these two weights, the percentage (%) of trimming loss was measured. It was calculated by following formula:

Trimming loss (%) =

$$\frac{\text{Weight (g) before trimming} - \text{Weight (g)after trimming}}{\text{Weight (g)before trimming}} \times 100 \qquad (3.2)\ [159]$$

Testing Sample Preparation:

Some sample dried fish Silver belly (LeiognathusBindus), Bombay duck (Harpodonnehereus), and Silver Jewfish (Otolithoides argenteus) were taken randomly, and separately were chopped. Then the fish sample was ground with an electric blender to make a homogeneous (Figure 3.9). This sample was used for proximate composition analysis.

Figure 3.9: Sample Preparation

Crude Protein Analysis:

The crude protein concentration was determined using the Kjeldahl technique. Among the reagents used were concentrated H_2SO_4, digestion mixture (Potassium sulfate 100gm+ Copper sulfate 10gm+ Selenium powder 1gm), NaOH solution (35%), 4 % boric acid solution, 0.1 gm mixed indication in 100 ml ethanol, combine bromocresol green and 0.1 g methyl red, and standard HCL (0.2N). The steps are followed for the estimation of protein:

Digestion: About 0.3 gm grinded sample was taken in the digestion tube. Then 8 ml of concentrated H_2SO_4 and 4gm digestion mixture was taken in the tubes. After that, digestion tubes were placed on the heating device of Kjeldahl apparatus (DK 20/26) and were heated for 1 to 1.5 hours at 400^0C. The end point of the digestion tube was cooled at room temperature before distillation.

Distillation: About 25 ml of distilled water was added to the digestion tube and 25 ml of NaOH was also added to the tube to make the solution adequately alkaline. Conical flasks containing 10 ml of boric acid with 2-3 drops of the mixed indicator were placed under the condenser to collect the distillate in the distillate unit (Figure 3.10). The distillation was completed within 4 minutes when the collected distillate was about 100ml and the distillate color shows dark greenish color.

Figure 3.10: Distillate Unit (VELP- UDK129)

Titration:

The collected distillate was titrated with standard HCL. The end point was indicated by light pinkish color. The protein content proportion was calculated using the following formula:

$$\text{Nitrogen (\%)} = \frac{(A-B)\times Normality\ of\ acid \times Milli\ equivalent\ weight\ of\ N2\ (0.014)}{Weight\ (g) of\ sample} \times 100 \qquad (3.3)$$

[158]

Where, A= ml of titrant of the sample, B=ml of titrant of the blank.

Crude protein (%) = Nitrogen (%) ×6.25 (3.4) [158]

Fat Content Analysis:

A Soxhlet device was used to determine the fat content of these (Figure 3.11). At first, weigh the empty beaker, and then fill it with 75 ml of ether. Exactly 2 grams of sample was obtained in the thimble paper. Boiling was done for 15 minutes, rising for 25 minutes, and extraction was done for 10 minutes, with the temperature of the Soxhlet apparatus set at 100^0C throughout the operation. Most of the solvent had evaporated after about 10 minutes.

The following formula was used to calculate

$$\text{Fat content: } (\%) = \frac{W1-W2}{W} \times 100 \qquad (3.5)\ [158]$$

Here, W_1 = weight of evaporated flask with the sample, W_2= weight of empty flask, W= weight of the sample

Figure 3.11: Soxhlet Device (FOOD ALYTRD40)

Ash Content Analysis:

3 grams of powdered material was placed in a pre-weighted porcelain crucible in triplicate. After that, the crucibles were placed in a muffle furnace (Figure 3.12) and heated to 550^0C for 6 hours. The crucibles were then placed in desiccators to cool for 30 minutes.

Figure 3.12: Muffle Furnace (Nabertherm-L9/13)

The percentage of residual components in each sample was calculated. It was calculated using the formula:

Ash content (%) = $\frac{\text{weight (gm) of ash}}{\text{Weight (gm)of sample}} \times 100$ (3.6) [158]

Moisture Content Analysis:

Empty crucibles were first dried in a hot air oven for 1 hour at 180^{0}C. The sample was then placed in a pre-weighed porcelain crucible using an electric balancer (Figure 3.13)

Figure 3.13: Hot Air Oven (BINDER-ED115)

After that, the crucible was placed in a hot air oven (BINDER-ED115) set to 105^{0}C for about 12 hours, or until the appropriate weight was reached. After that, the crucible was weighed once more. The moisture loss was determined from these weights using the following formula:

Moisture Content (%)

$$= \frac{Weight\ of\ wet\ material(g) - Weight\ of\ dry\ material(g)}{Weight\ of\ wet\ material\ (g)} \times 100 \quad (3.7)$$

[158]

Drying Rate:

Drying is a phenomenon of simultaneous mass and heat transfer. Drying is mostly used to remove water from food-related items. The drying system must provide energy for the evaporation of water. The sample drying rate was calculated using the following formulae.

$$DR = \frac{W_i - W_{i+1}}{t} \quad (3.8)\ [156]$$

Where DR is the drying rate (gm /Sec.); W_i= initial weight of fish sample, w_{i+1} = Immediate final weight and t is drying time (Sec.)

3. 1.9 Microbial Analysis of Dried Fish:

Bacteriological study was conducted according to AOAC and FDA BAM method [160]. Both qualitative and quantitative microbial analysis was conducted of these dried samples. Quantitative analysis was performed through Total Plate Count (TPC) method.

Total Plate Count

Media Preparation: Plate count agar is a commercial preparation and was used for the determination of total viable bacteria in these samples. The media was prepared through taking exactly 23.5gm of agar (plate count agar, hi media) and mixed with 1000 ml of distilled water and boiled to dissolve the ingredients completely. Then the media was sterilized at 121^0C for 15 minutes under 15 bs/inch^2 Pressure in an autoclave (DAC-60). Then the sterilized agar was placed in the previously sterilized petri-dishes by using bio safety cabinet (JSCB-1200SB). After solidification of agar media petri-dishes were placed in incubator (Figure 3.14) at 37^0C for 24 hours at inverted position.

Figure 3.14: Incubator (BINDER-DIN12880)

Serial dilution and sample inoculation: Consecutive decimal dilution technique was used in the TPC method. Stock solution of sample was prepared through taking 9 ml of 0.85% physiological saline and 1 gm of sample and blending for 3 minutes. For serial dilution 5 test tubes were selected which contain 9 ml of distilled water. Then 1 ml of stock solution was transferred to 1st test tube. In this way 10-1, 10-2, 10-3, 10-4, 10-5, decimal dilution was pipette into pre-prepared agar plate. The sample was separated in agar plate by using glass beads. The petri-dishes were incubated at 37^0C for 24 to 48 hours. After incubation, counted the colonies through colony counter (KMC-1300V) and petri-dishes which had a range 30 to 300 colonies were accepted. There is sufficient evidence that 10-1 and 10-2 dilution contain more than 300 colonies, for the reasons two dilutions were not usually used in the total plate count method [161]. The total bacterial colony was determined by following formula;

Colony forming unit (CFU/g) $= \frac{\text{No of colonies} \times \text{dilution factor} \times 10}{\text{Weight (g) of sample}}$ (3.9) [158]

3.2 STATICAL ANALYSIS

Each experiment and measurement were repeated three times. The results shown were the mean with standard deviation (S.D.). Standard deviation (SD) is used to determine the variability of data across different observations. The standard error of mean was also used to calculate the accuracy of the average values. The following equations can be used to calculate standard deviation SD (and) standard error of mean:

Standard deviation, $\sigma = \sqrt{\frac{\sum_{i=1}^{n}(xi-\bar{x})}{n-1}}$ (3.10) [165]

Standard Error of the Mean (SEM): $\sigma = \frac{\sigma}{\sqrt{N}}$ (3.11)[165]

Where, $\sum M$ = Mean of the Standard error, $\sigma =$ standard deviation

Xi = Each value of the data, n= Number of the values

N = Number of the observations

3.3 COST ANALYSIS

In order to make the process of comparing designs of off-grid and grid-connected power systems for a range of applications simpler, this analysis makes use of HOMER, the micropower optimization software created by Mistaya Engineering in Canada for the National Renewable Energy Laboratory (NREL) in the United States. While constructing a power system, many choices must be taken regarding the configuration of the system, such as which components to include, how big to make each component, etc. Many technological possibilities, a range of technological prices, and the accessibility of energy resources make these decisions difficult. The HOMER optimization and sensitivity analysis methods make it simpler to assess the numerous potential system configurations [166]. By running energy balancing calculations and showing a list of outcomes, HOMER simulates system operation.

3.4 IMPLEMENTATION OF HOMER CODE

3.4.1 System Equipment Configuration:

Figure 3.15 shows the equipment considered in the optimization. Photovoltaic solar cells, a converter, a battery bank, and a loading system are the pieces of equipment that have been considered. Table 3.1 below shows the size of the components under consideration, the cost of acquisition, replacement, operation, and maintenance, as well as the estimated lifetime as input into the HOMER software.

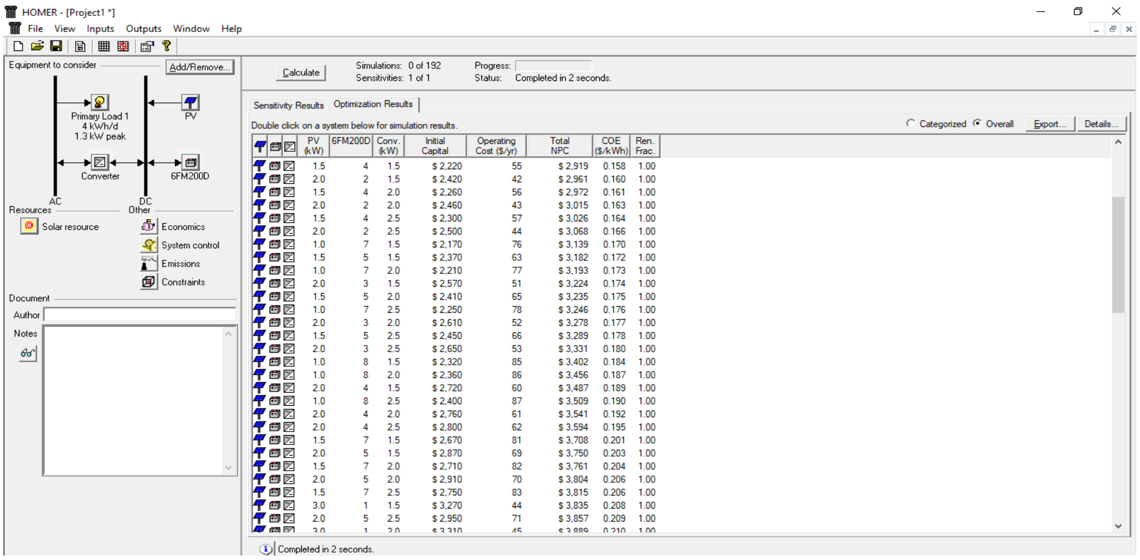

Figure 3.15: Equipment Considered in The Optimization

Table 3.1: System Components

Component	Size	Capital Cost ($)	Replacement Cost	O&M Cost ($)	Life time
PV Panels	2KW	$2000/KW	624	0	20 years
Vision6 FM200D Battery	200 Ah /12 Volt	$300/ Battery	$261/Battery	$2/Year	917KW life time throughput per battery
Converter	1.5 KW	$120/KW	$50/KW	0	15 years

3.5 SYTEM PERFORMANCE:

3.5.1 PV System:

Capital and replacement costs were set at $1.0/W. The PV system's maintenance costs were not considered because the panels require little or no maintenance. A derating factor of 80% and a lifetime of 20 years were considered, as shown in Figures 3.16 and 3.17 below. Our solar photovoltaic cell calculation result was 800 watts, we used it practically in my experimental setup. In homer software simulation we used three different solar PV module which is 1kw, 1.5 Kw, 2Kw for maximum simulation result.

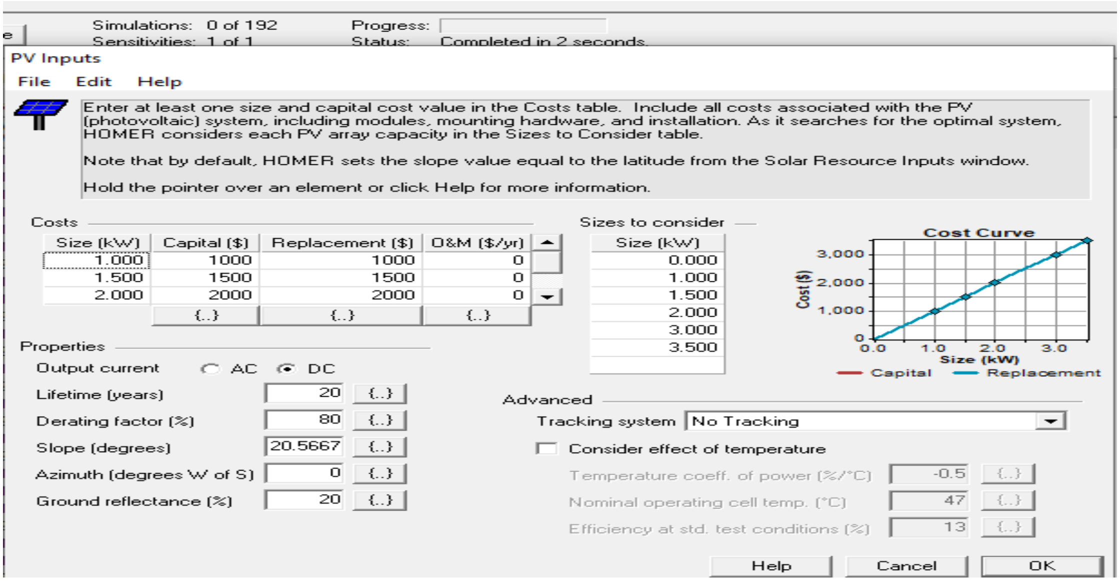

Figure 3.16: Photovoltaic Solar Input

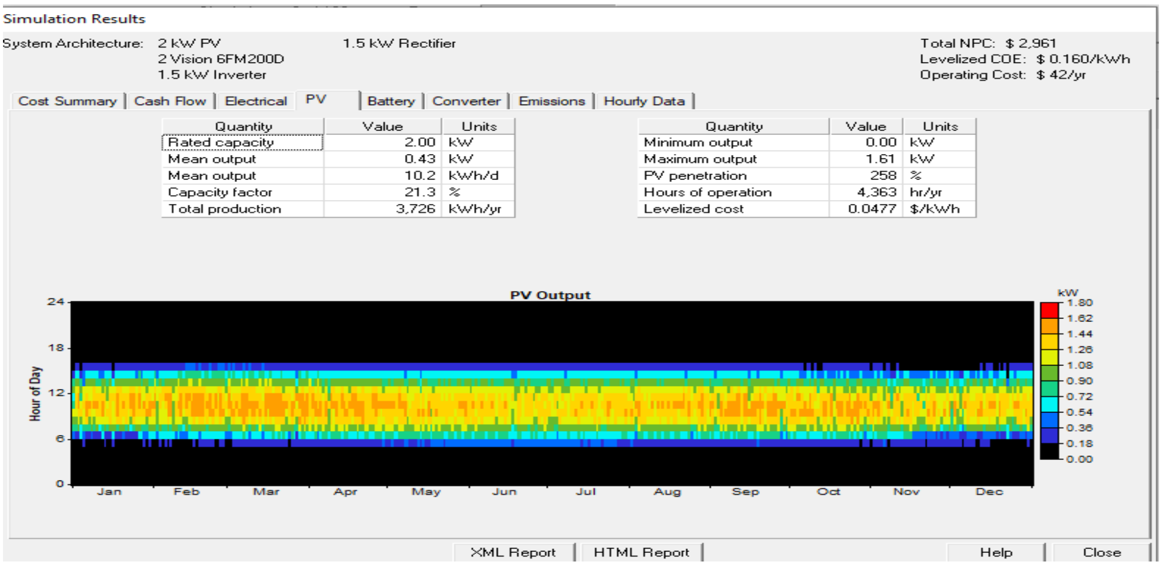

Figure 3.17: Photovoltaic Solar Output

3.5.2 Battery Storage:

The 6FM200D series was selected as the battery. It has a nominal capacity of 200Ah and a nominal voltage of 12 Volts (2.4 kWh). HOMER took into account two batteries in the scenario depicted in Figures 3.18 and 3.19 below.

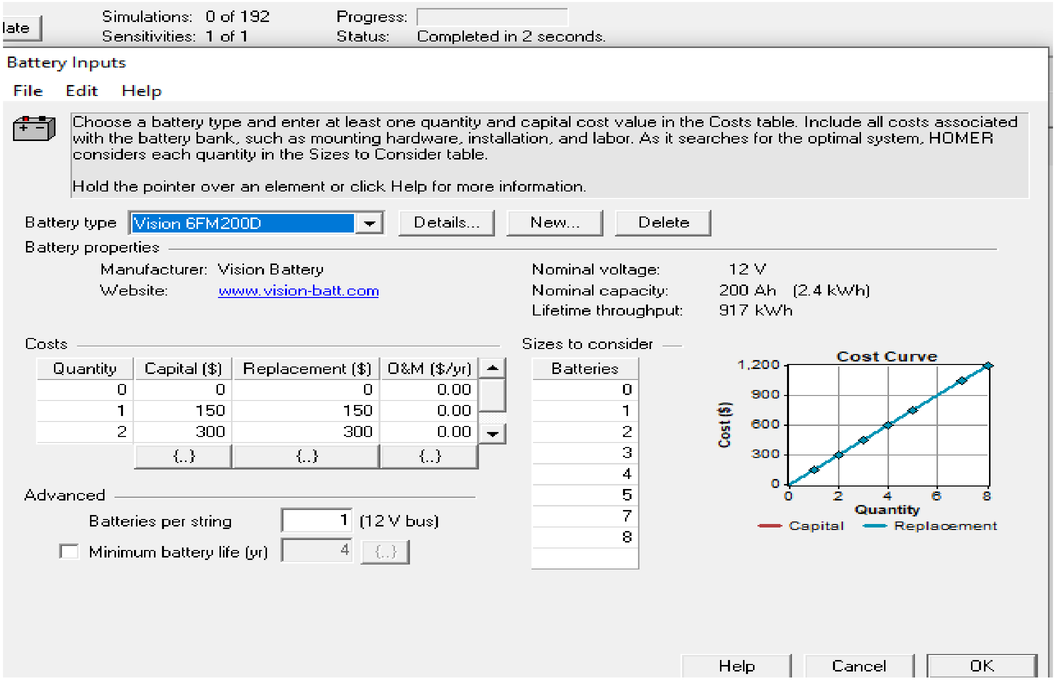

Figure 3.18: Storage Batteries Input

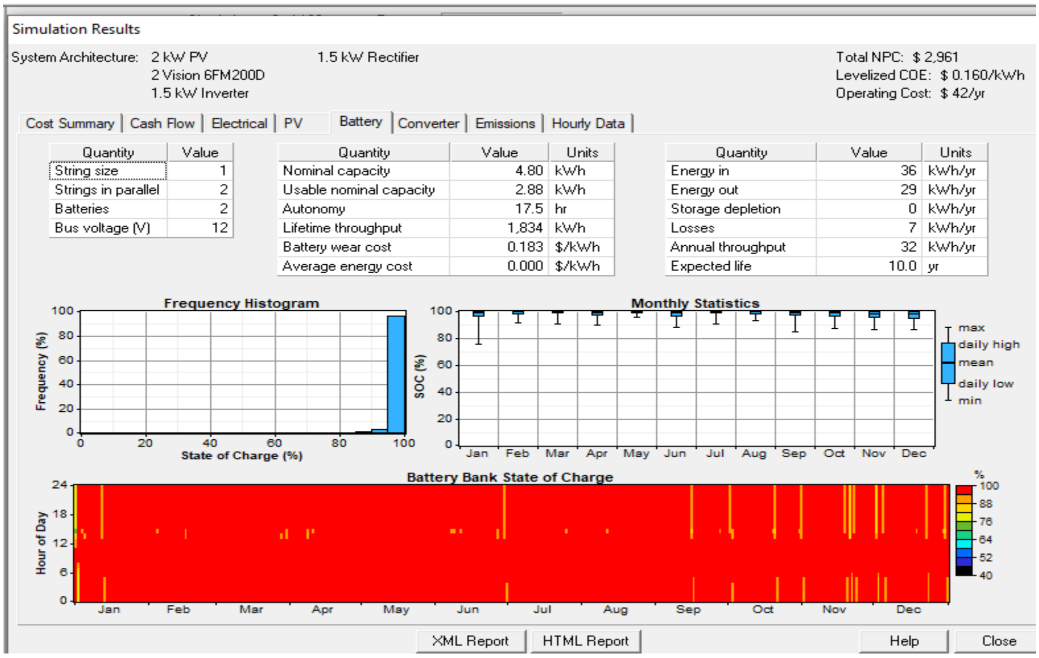

Figure 3.19: Battery Bank State of Charge

3.5.3 Converter and Inverter

For all sizes considered, the inverter and rectifier efficiencies were assumed to be 90% and 85%, respectively. The sizes under consideration ranged from 1.2kW to 1.5kW. Figure 3.20 depicts the input of the converter.

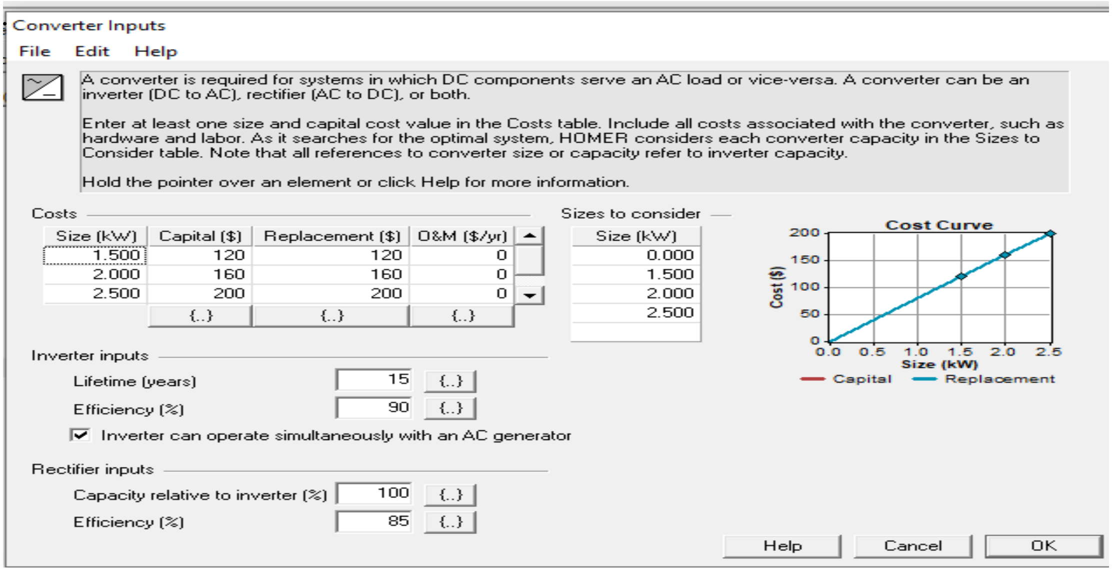

Figure 3.20: Converter Input

3.5.4 Load Levels

As shown in Figure 3.21, a typical air blast dry oven and microwave oven load was considered.

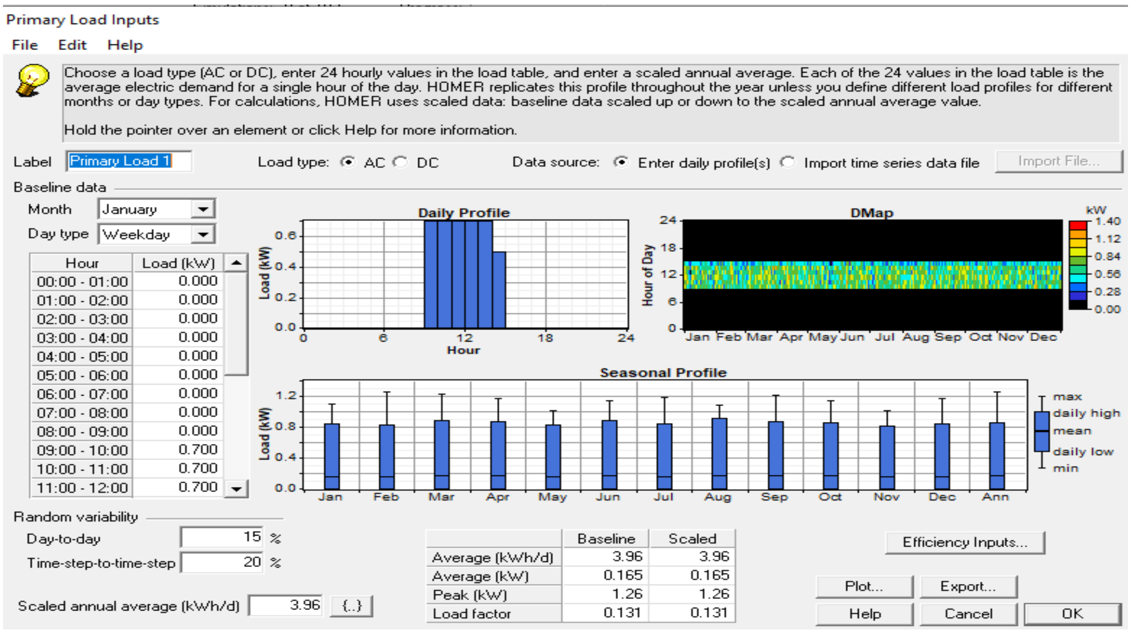

Figure 3.21: Drying Profile of The System

3.5.5 Summary of Cash Flow

Figures 3.22 and 3.23 show the total net present cost of HOMER's main economic output.

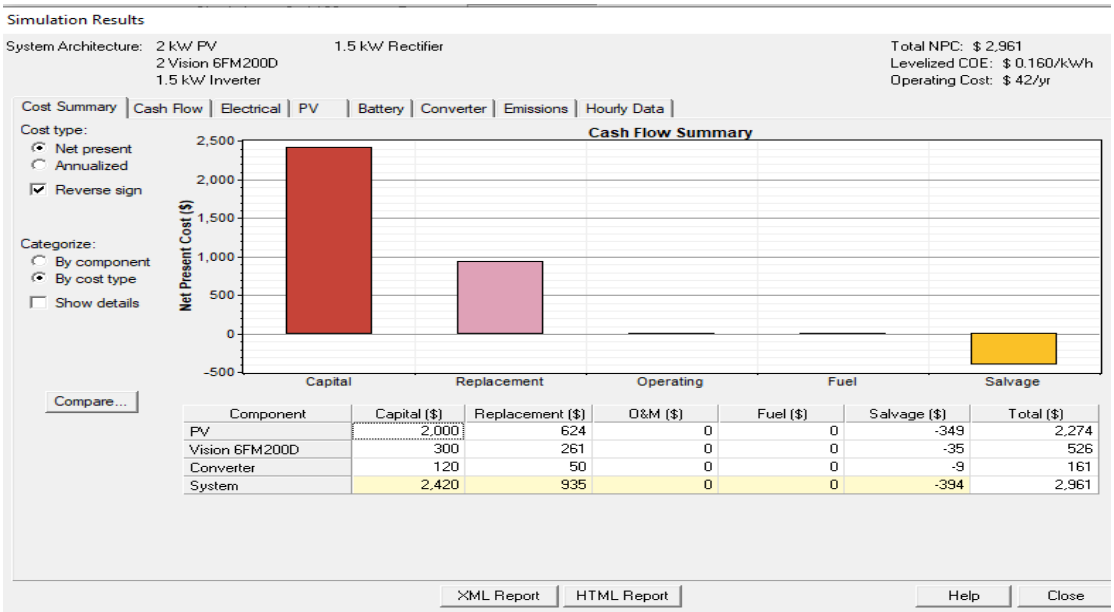

Figure 3.22: Summery of Nominal Cash Flow

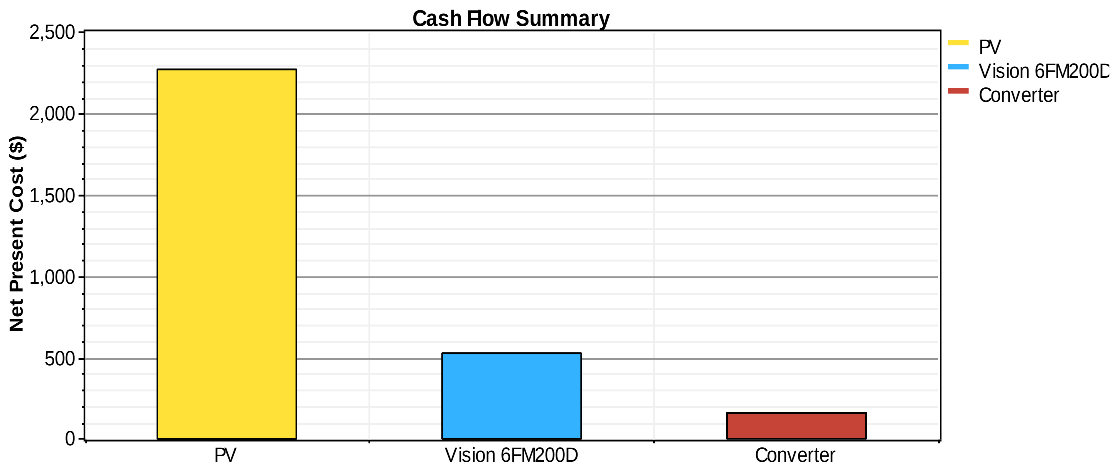

Figure 3.23: Nominal Cash Flow for Selected Components.

The net present cost is used to rank each system, and all other economic outputs are evaluated in order to get the net present cost. The outcome of the optimization results in an initial capital cost of $2420 and an operating cost of 935 dollars per year. With a total net present cost (NPC) of $2961 and an energy cost (COE) of 0.160 $/KWh (16 BDT/KWh), respectively. The utility bill and the net cost of the hybrid system were compared. Furthermore, it was found that using a hybrid energy system as opposed to just a generator-based energy system significantly reduces greenhouse gas emissions.

In general, the created algorithm's cost estimate is about greater than the HOMER's cost estimate for the identical thing.

3.6 PAYBACK PERIOD

The designed microwave solar dryer can dry up to almost 2 kg of dry fish, if the running hour setup is 6 hours a day.in the one month, the amount of dried fish sample will be 60 kg. As the setup is Lab-scale, The cost seems higher in comparing the capacity of drying per month. However, pilot or industrial scale definitely reduce the average running cost. But, after a certain amount of time, this system may serve as a good source of revenue as well as a good source of economic profits. The payback period could be computed using the formula below.

Payback period = I/(R-E) (3.12)

Where, I: Investment, R: Return, E: Expenses.

We will calculate the price of hot air microwave solar dryer. The total cost of the experimental setup was $2961 or 290000 BDT/Tk.

Payback period of Hot air- Microwave Drying:

Bombay Duck Fish

We need raw Bombay duck fish yearly = 4kg×30×12=1440kg

1 kg raw Bombay duck fish 100 Tk, so total taka need=1440×100=14,4000 Tk

So daily produced of dried 2kg Bombay duck fish and per month we produced 60 kg dried fish.

Then yearly we produced dried Bombay duck fish 60kg ×12= 720 kg

720 kg dried fish market price =(720×600)=432000 Tk

Payback period = 290000+144000/432000

= 1 year

Silver Belly Fish

We need raw Silver belly fish yearly = 3kg×30×12=1080kg

1 kg raw Silver belly fish 250 Tk, so total taka need= 250×1080= 270000 Tk

So daily produced of dried 2kg Silver belly fish and per month we produced 60 kg dried fish

Then yearly we produced dried Silver belly fish 60kg ×12= 720 kg

720 kg dried fish market price = (720×800) =576000 Tk

Payback period = 290000+270000/576000

= 9 months

Silver Jew Fish

We need raw Silver jew fish yearly = 3kg×30×12=1080kg

1 kg raw Silver jew fish 300 tk, so total taka need= 300×1080= 324000 Tk

So daily produced of dried 2kg Silver jew fish and per month we produced 60 kg dried fish

Then yearly we produced dried Silver jew fish fish 60kg ×12= 720 kg

720 kg dried fish market price = (720×900) =648000 Tk

Payback period = 290000+324000/576000

= 1 year

So, running solar based setup will pay for compensate for 1 year. And its working life estimated to be 20 years during that time it will produce highly nutritious dried fish.

Natural Fish Drying:

Bombay Duck Fish

Traditional sun drying required an average drying time 3-4 days for Bombay duck fish drying. In microwave drying we produced 2kg dried Bombay duck fish in single day. But same amount of dried fish produced in natural drying need about 4 days.

Yearly we need Bombay duck fish= 1440 kg

1 kg raw Bombay duck fish 100 Tk, so total taka need= 1440×100=14,4000 Tk

Labour cost Monthly need = 16000Tk

Yearly need= 12×16000=192000/- Tk

Fence and net cost yearly = 20,000/-

Total Cost= (Raw fish + Labour cost + Fence & net cost)

= 144000+192000+ 20000 = 356000/- Tk

Then yearly we produced dried Bombay duck fish 60kg ×12= 720 kg

720 kg dried fish market price = (720×700) = 324000/- Tk

Payback period = 356000/324000

= 1 year 9 days

Silver Belly Fish

Traditional sun drying required an average drying time 4-5 days for Silver Belly fish drying. In microwave drying we produced 2kg dried Silver Belly fish in single day. But same amount of dried fish produced in natural drying need about 5 days.

Yearly we need Silver Belly fish= 1080 kg

1 kg raw Silver Belly fish 250 Tk, so total taka need= 1080×250=270000Tk

Labour cost Monthly need = 16000Tk

Yearly need= 12×16000=192000/- Tk

Fence and net cost yearly = 20,000/-

Total Cost= (Raw fish + Labour cost + Fence & net cost)

=270000+192000+ 20000 = 482000/- Tk

Then yearly we produced dried Silver Belly fish 60kg ×12= 720 kg

720 kg dried fish market price = (720×650) =468000/- Tk

Payback period = 482000/468000

= 1-year 2days

Silver Jew Fish

Traditional sun drying required an average drying time 3-4 days for Silver Jew fish drying. In microwave drying we produced 2kg dried Silver Jew fish in single day. But same amount of dried fish produced in natural drying need about 5 days.

We need raw Silver Jew fish yearly =1080kg

1 kg raw Silver Jew fish 300 Tk, so total taka need= 300×1080= 324000 Tk

Labour cost Monthly need = 16000Tk

Yearly need= 12×16000=192000/- Tk

Fence and net cost yearly = 20,000/-

Total Cost= (Raw fish + Labour cost + Fence & net cost)

=324000+192000+ 20000 = 536000/-

So daily produced of dried 2kg Silver Jew fish and per month we produced 60 kg dried fish.

Then yearly we produced dried Silver Jew fish 60kg ×12= 720 kg

720 kg dried fish market price = (720×700) = 504000Tk

Payback period = 536000/504000

= 1 year 6 days

As shown in the above payback periods for natural and microwave drying, payback time is shorter for hot air microwave drying than natural drying.

CHAPTER 4

RESULT AND ANALYSIS

4.1 DRYING OF MARINE FISH

4.1.1 Percentage (%) of Drip and Trimming Loss and Pre-Dried of Raw Fish.

The percentage of pre-dried fish sample which prepared from raw fish by using hot air dryer is also presented in Table 4.1. An increase in microwave power resulted in a decrease in moisture content of fish, the difference is obvious in starting point for the microwave drying regarding moisture content due to the air temperature. Initial condition of Bombay duck raw fish weight was 1000 gm to decreased 606 gm after pre-dried fish sample, Silver Jew Fish 1000 gm to decreased 782 gm and Silver Belly fish 1000 gm to decreased 611 gm after the 5-hour hot air-drying constant temperature 50^0C and air velocity of 1.5m/s. Then was it ready for microwave heating.

Table 4.1: Drip Loss, Trimming Loss and Pre-Dried percentage (%) of Raw Fish.

Fish Species	Initial Weight (gm)	Weight after receiving (gm)	Weight after trimming (gm)	Pre dried fish (gm)	Drip loss (%)	Trimming loss (%)	Dry % of pre-dried fish
Bombay Duck	1000	960	935	606	4	6.5	39.4
Sliver Jew	1000	970	915	782	3	8.5	21.8
Silver Belly	1000	979	896	611	2.1	10.4	38.9

4.1.2 Effect of Microwave Power and Air velocity on Moisture Content.

The higher evaporation of water from the fish's surface and within when temperatures rise as a result of microwave heating may be the cause of the reduced moisture content. However, the drying curves differed dramatically under varied microwave power conditions. The microwave power has a substantial effect on the moisture content of pre-dehydrated fish.

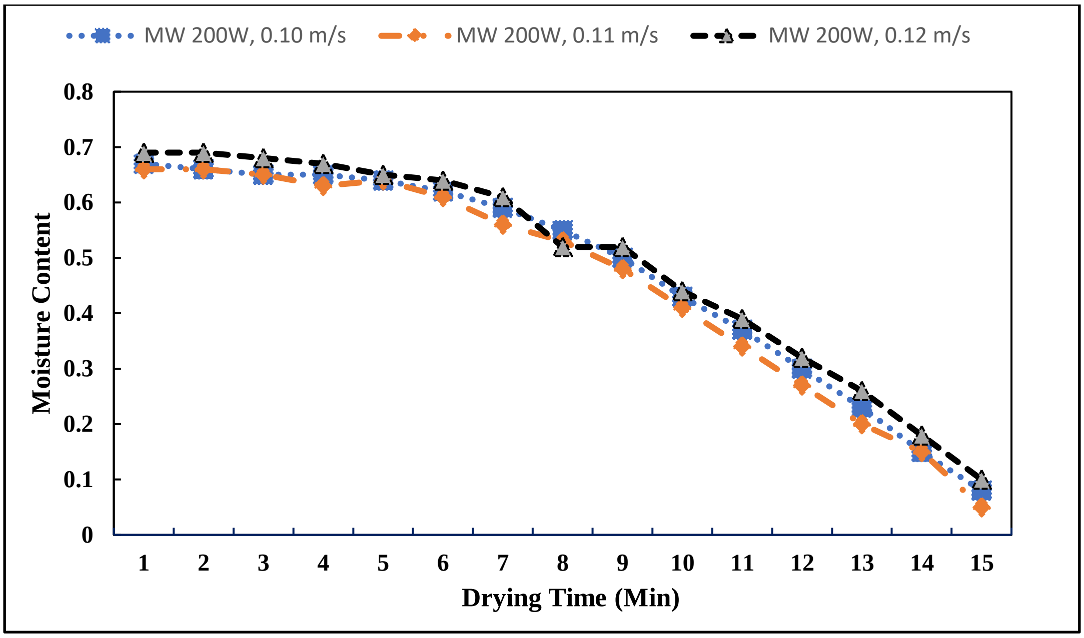

Figure 4.1: The Effect of the Air Velocity on Moisture Content of Bombay Duck fish From Microwave (400w).

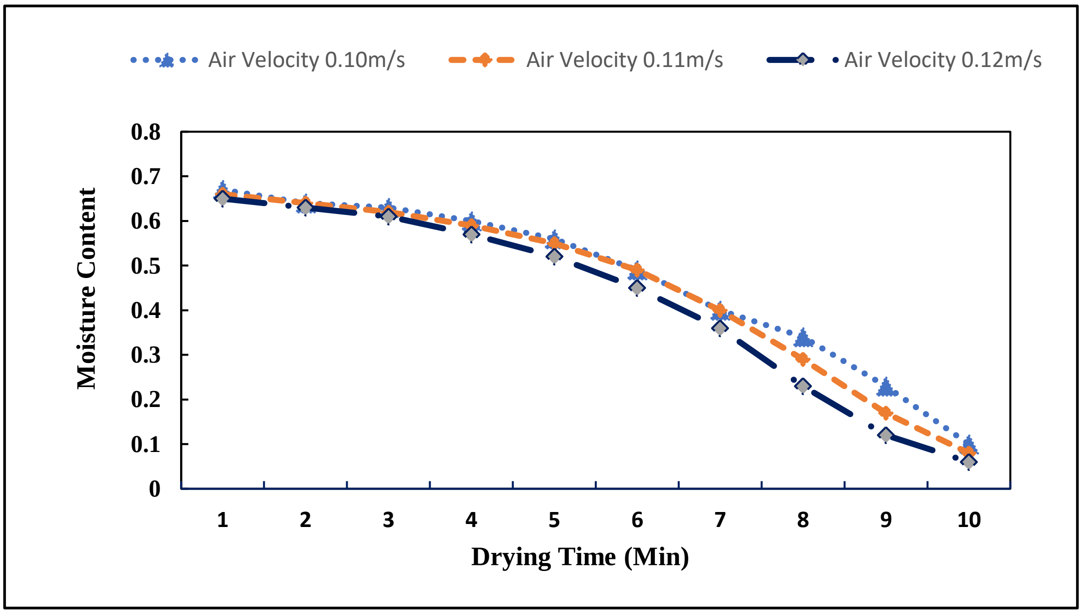

Figure 4.2: The Effect of the Air Velocity on Moisture Content of Bombay Duck fish From Microwave (200w).

It is seen that the drying time (Figure.4.1 and Figure 4.2) of Microwave drying time 400-watt at three different air velocity (0.1 m/s, 0.11 m/s, 0.12 m/s) is less (9-11 min) than 200 watt (14-15 min). The period of drying for Bombay duck dried fish was reduced along with the increase in microwave power. For Better review another two fish sample (Silver Jew and Silver belly fish) were tested for 200w and 400 w at 0.1

m/s. Similar result was found that (Figure 4.3 and Figure 4.4) for MW 400w is less (10 min) than MW 200w (15 min) respectively. It can be seen from the figure that the wind speed flowing 0.12 m/s can cause moisture in less time than the velocity of the wind flowing in the other two ways. As a result, 200 watts, 0.12 m/s takes relatively less time.

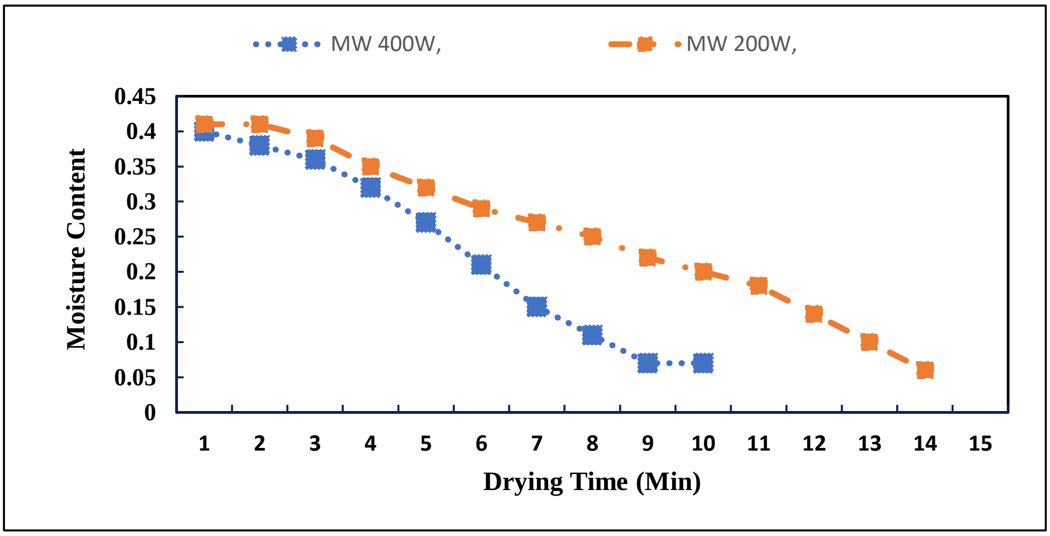

Figure 4.3: The Effect of Microwave Power on Moisture Content of Silver Jew fish at Constant Velocity (0.1 m/s).

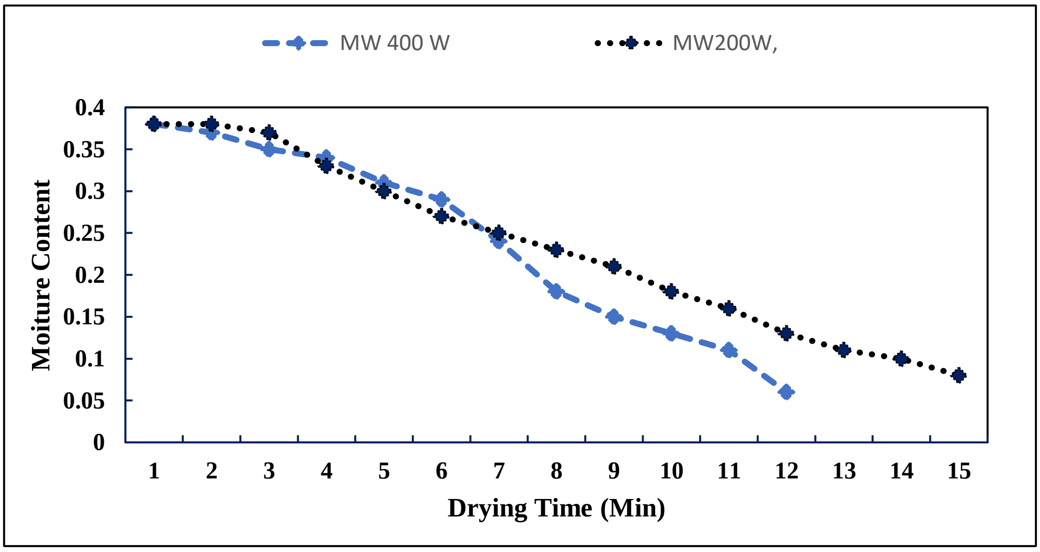

Figure 4.4: The Effect of Microwave Power on Moisture Content of Silver Belly fish at Constant Velocity (0.1 m/s).

The moisture content of the fish throughout the microwave drying stage was significantly influenced by the temperature of the hot air pre-drying. The higher the hot air temperatures, the faster the samples dried. Similar results have been observed for vegetable materials drying [161].

4.1.3 Effect of Temperature and Air velocity on Moisture Content.

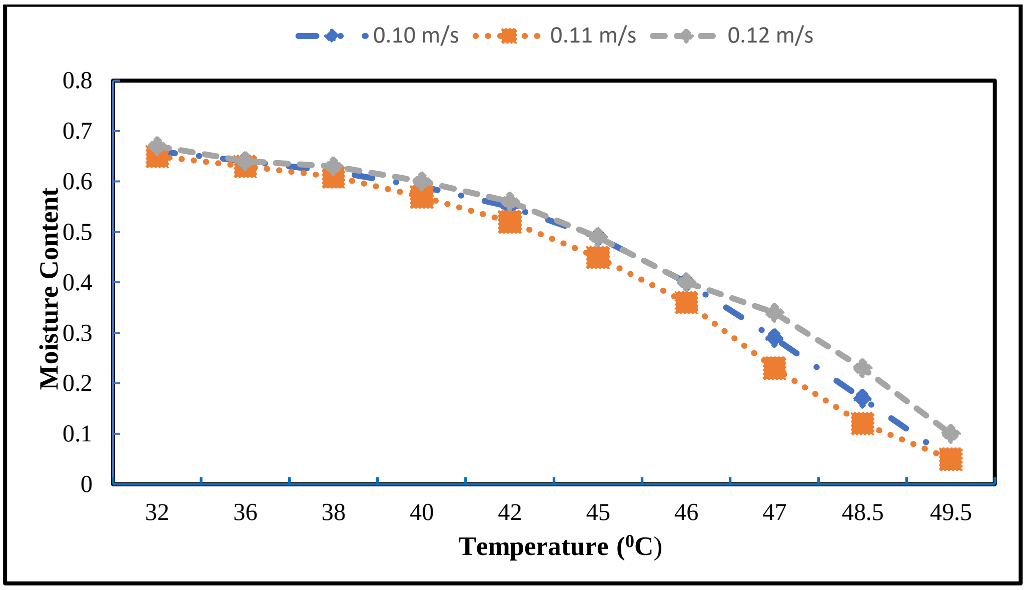

Figure 4.5: The Effect of the Temperature on Moisture Content of Bombay Duck fish From Microwave (400w).

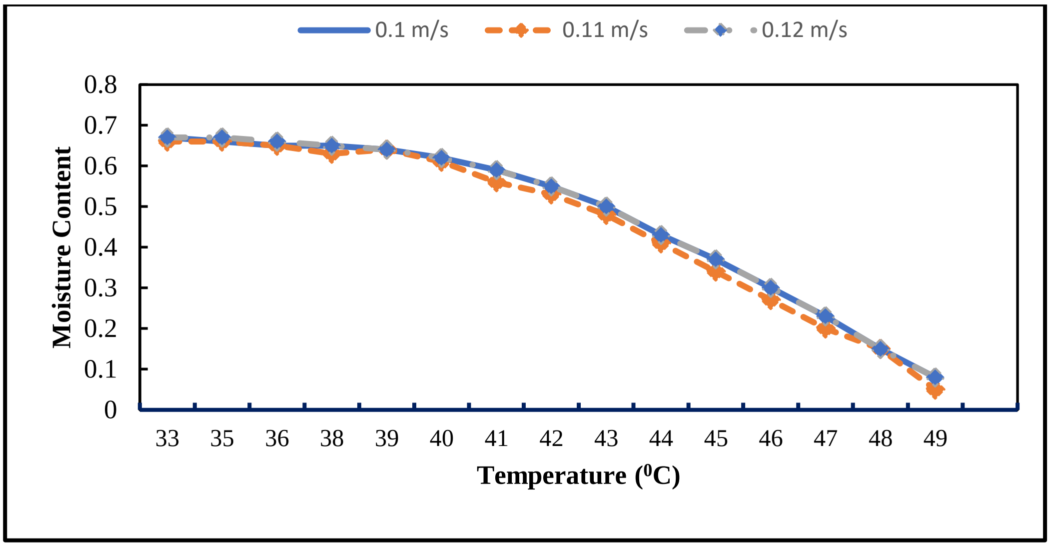

Figure 4.6: The Effect of the Temperature on Moisture Content of Bombay Duck fish From Microwave (200w).

The figure 4.5 and figure 4.6 shows the temperature relationship with the moisture. It can be seen from the figure that the amount of moisture decreases as the temperature increases over time. The moisture content was recorded low at a time around 49.5 ^{0}C, which is below moisture content 0.10. As a result, the fish are converted into dried fish.

4.1.4Effect of Microwave Power and Air velocity on Drying Rate.

Initially, when the amount of moisture was high, the drying rate increased over time under all drying conditions, which corresponds to a transition period, but as the moisture content decreased, the drying rate continued to decline. The lack of a constant rate suggests that the internal the microwave absorption of energy throughout the falling rate drying was what drove moisture removal[162]. Figure 4.7, Figure 4.8 shows the significant differences in drying rate (Eq. 3.10) of Bombay duck fish.

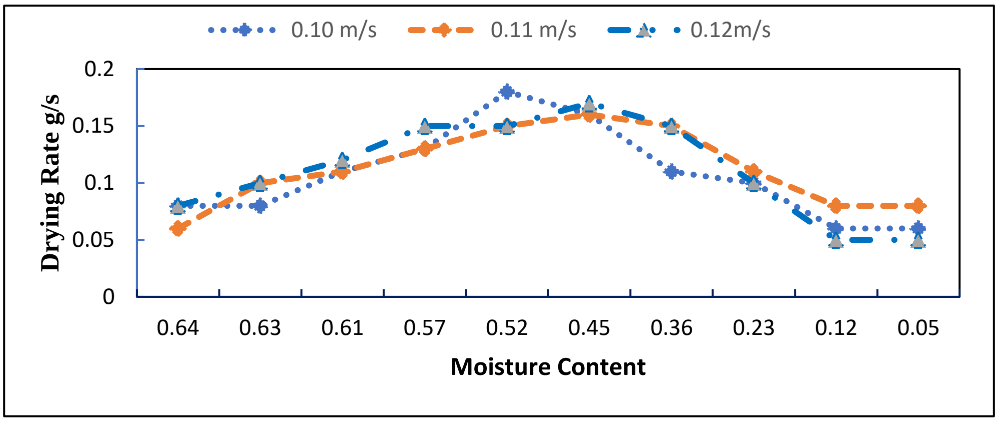

Figure 4.7: Effect of Moisture Content on Drying Rate on of Bombay Duck Fish for 400w Microwave at Different Velocity.

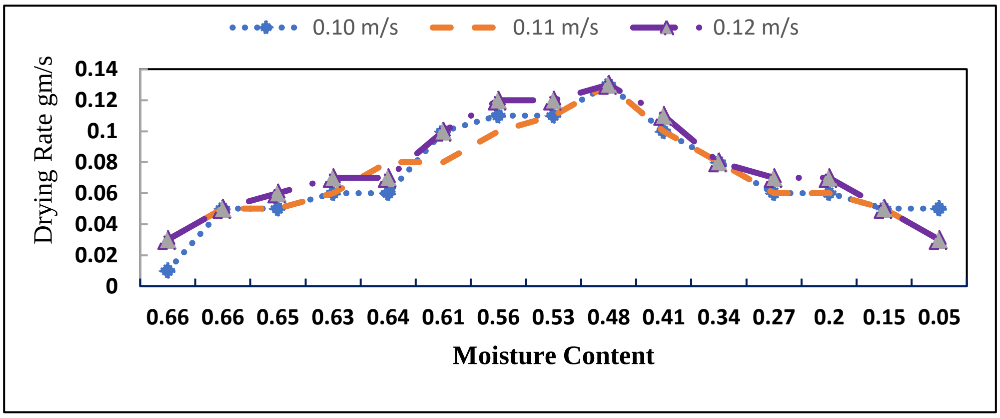

Figure 4.8: Effect of Moisture Content on Drying Rate of Bombay Duck Fish for 200w Microwave at Different Velocity.

For 200-watt and 400 watts at different air velocities (0.10 ms.^{1}, 0.11 ms^{-1}, 0.12 ms^{-1}) the drying rate of the dried fish increase up to certain moisture content then further decrease drying rate with moisture content in almost all the cases. The moisture content in the product was quite high during the early drying phase, resulting in higher microwave power absorption and higher drying rates because of increased moisture diffusion. Similar results were found for Silver Jew and Silver Belly fish (Figure 4.9 and Figure 4.10)

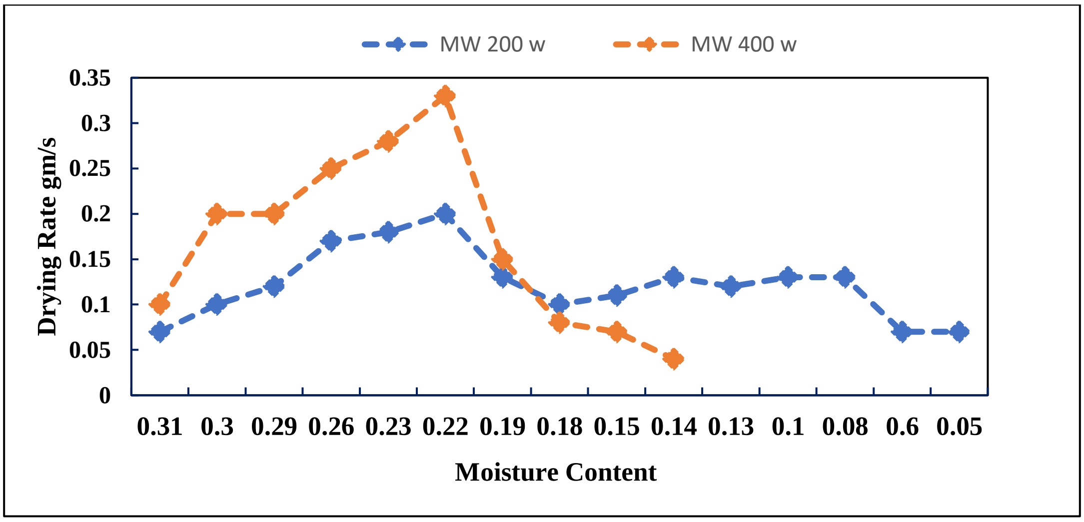

Figure 4.9: The Effect of Moisture Content on Drying Rate of The Silver Jew fish for Different Microwave Power.

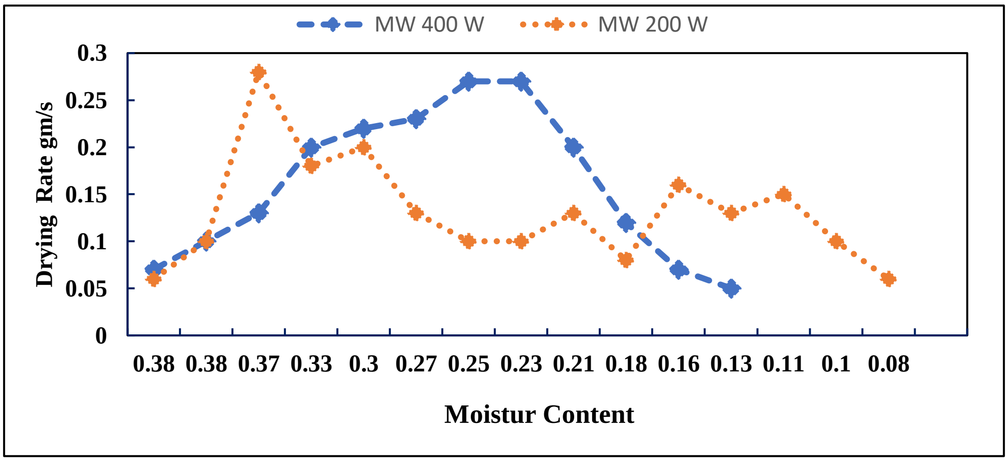

Figure 4.10: The Effect of Moisture Content on Drying Rate of The Silver Belly fish for Different Microwave Power.

As drying progresses, the drying rate rapidly rises and then gradually drops. In general, it is noticed that drying rate reduces with time or with the lowering of moisture content. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power. As a result, both hot air temperature and microwave power are expected to improve the drying rate of dried fish. The required drying time was less than 10 min for 400 watts and 15 min for 200 watts obtaining the final products of 10% of moisture content when marine fish dried by microwave drying. However, it took at least 19 hours to dry the marine fresh fish to finished goods with the same moisture content using 50^0C of hot air dryer [164]. As a result, hot air-microwave drying may significantly reduce the needed drying time when compared to hot air drying of fish. Higher drying rates were obtained at higher microwave output powers. Thus, the microwave output power had a crucial effect on the drying rate.

4.2 NATURAL DRYING CHARACTERISTICS OF MARINE FISH.

The target fish is physically exposed to the sun in order to dry it. This is normally done outside in the open air, using solar energy to evaporate the fish's water content. The duration of fish drying is depended upon how quickly the moisture will be removed from the fish. The rate of drying is affected by a number of factors, including solar radiation, relative humidity, temperature and air velocity.

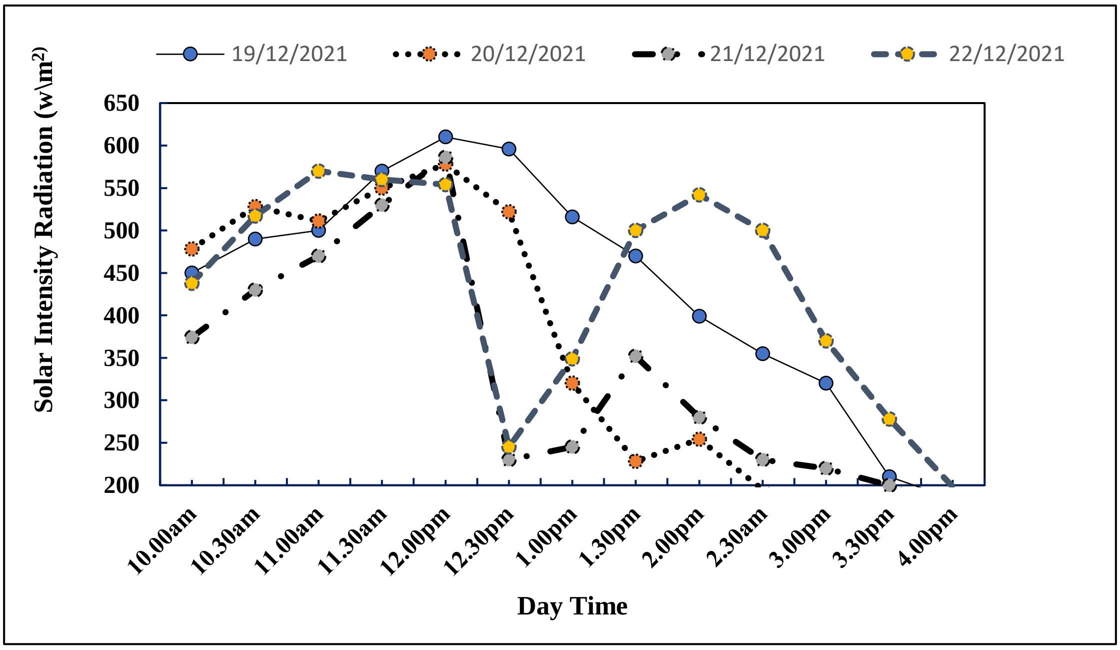

Figure 4.11: Solar Radiation in CUET in December 2021 During Silverbelly Fish Drying.

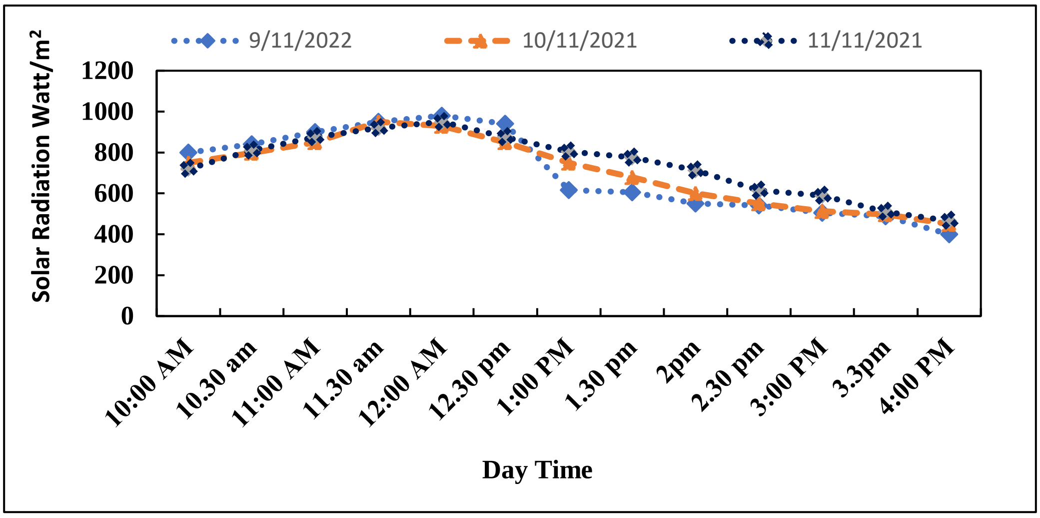

Figure 4.12: Solar Radiation in CUET in November 2021 During Bombay Duck Fish Drying.

Traditional sun-drying & Environmental data were collected from the Top floor of IET, CUET Academic Building during from 19/12/2021 to 22/12/2021 for silver belly fish drying and 09/11/2022 to 11/11/2022 for Bombay Duck fish. The evaporated water from the fish body was transported away by natural air. Figure 4.11, and Figure 4.12 shows the difference in intensity of solar radiation every half hour from 10 am to 4 pm on 19/12/2021 to 22/12/2021and 9/11/2022 to 11/11/2022. It is seen that the intensity of radiation of the sun is high from 10 am to 12.30 pm. The solar radiation measurements are taken using DS-05A solar meter.

As can be seen from Figure 4.13 and Figure 4.14 Date19/12/2021 to 22/12/2021 and 9/11/2022 to 11/11/2022 one of the elements of drying fish was Temperature which was observed more from morning to afternoon.

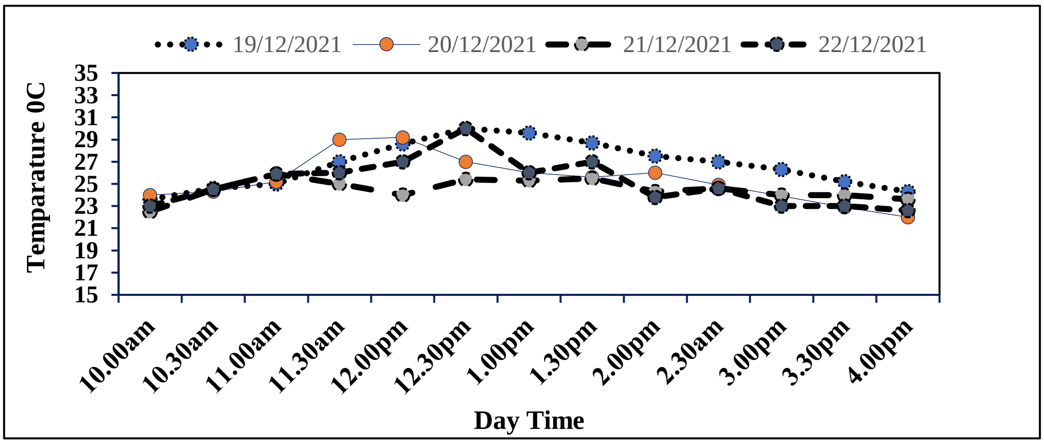

Figure 4.13: Temperature in CUET in December 2021 During Silverbelly Fish Drying.

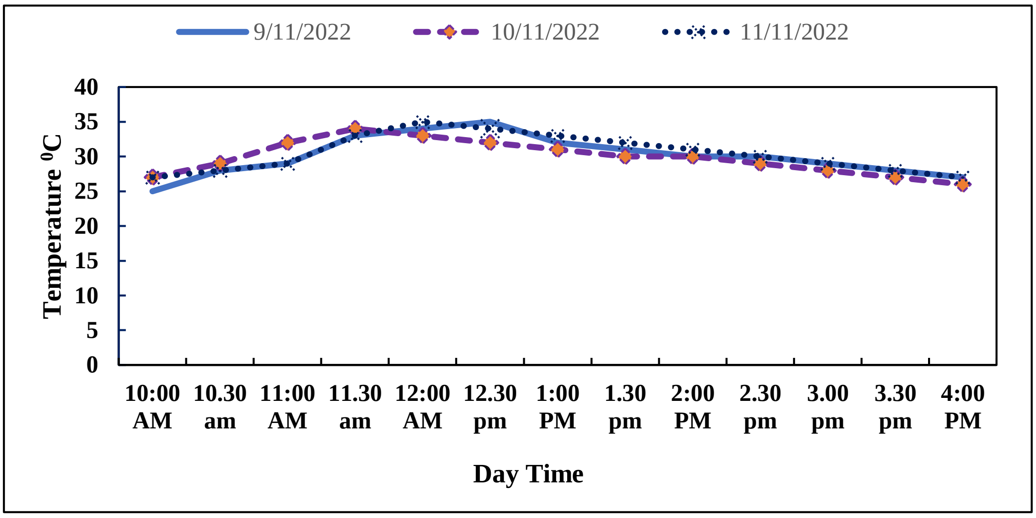

Figure 4.14: Temperature in CUET in November 2022 During Bombay Duck Fish Drying.

The maximum temperature of 30^{0}C at 12.30 pm was recorded for drying the fish on 22/12/2021 and 35^{0}C at 12.30 pm was maximum temperature in 11/11/2022 for fish drying. The temperature of the air is dropped below ambient at the start of drying after a short time, it achieves a stable value around 30^{0}C at 12-1.00 pm as shown in Figure 4.13, Figure 4.14 The heat energy required for evaporation is provided by the surrounding air. Warm air supplies more heat energy and the pace of drying accelerated if the air speed and relative humidity allow for rapid moisture remove.

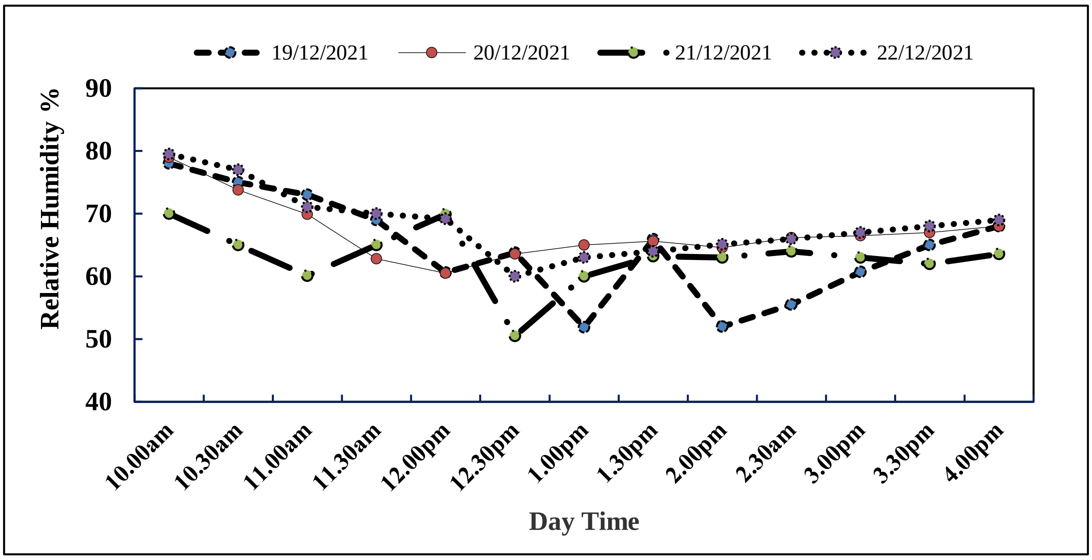

Figure 4.15: Relative Humidity in CUET in December 2021 During Silver Belly Fish Drying.

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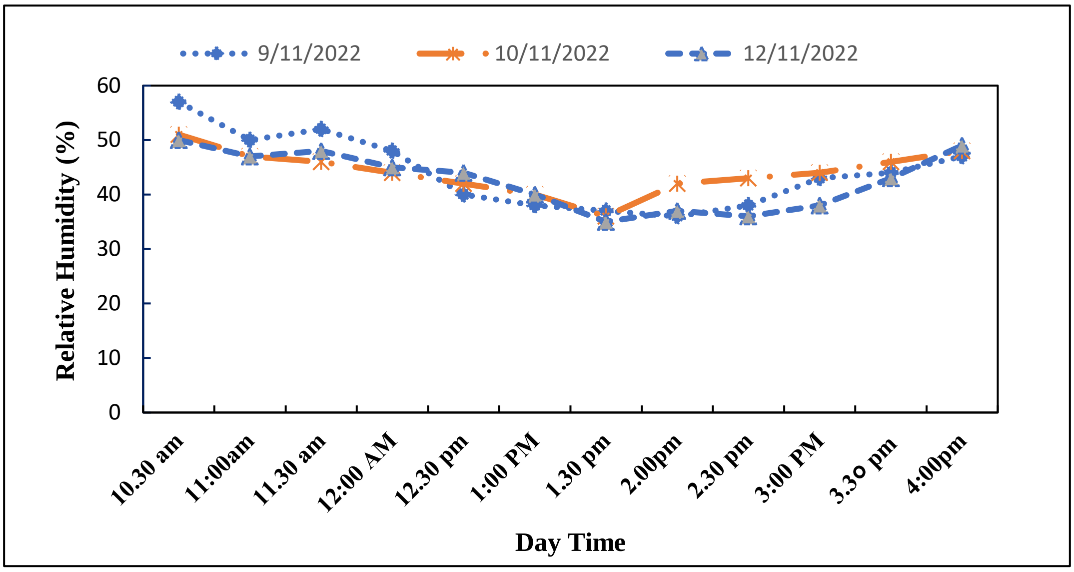

Figure 4.16: Relative Humidity in CUET in November 2022 During Bombay Duck Fish Natural Drying.

The temperature of the fish is reduced below ambient at the start of drying; after a short time, it reaches a steady value, and the heat energy required for evaporation is reasonable by the heat supplied by the surrounding air. Warm air can provide more heat energy, and if the air speed and relative humidity allow for rapid water movement, the rate of drying will be accelerated Figure 4.15 and Figure 4.16 can be seen that lower humidity is obtained where the temperature is higher. The phenomenon is observed during afternoon when the temperature is high and the relative humidity shows a minimum of 35% which play an effective role in drying the fish.

According to the data obtained from silver belly fishes and Bombay Duck fish's samples are given in the Appendices E and Appendices F. The moisture contents in respect of day time corresponding total hour of different days are represents in the Figure 4.15 and Figure 4.16. The moisture contents decreased with the increase in drying day time. If the resulting value is less than 0.1, the sample is considered sufficiently dry.

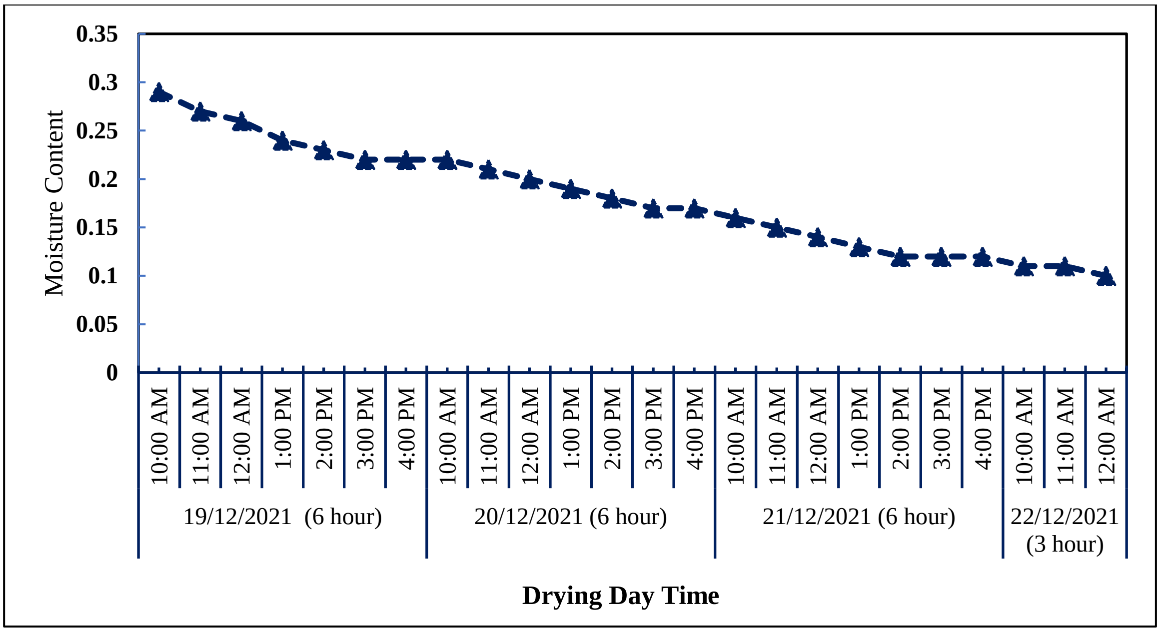

Figure 4.17: The Effect of the Drying Time on the Moisture Content of the Silver Belly Fish.

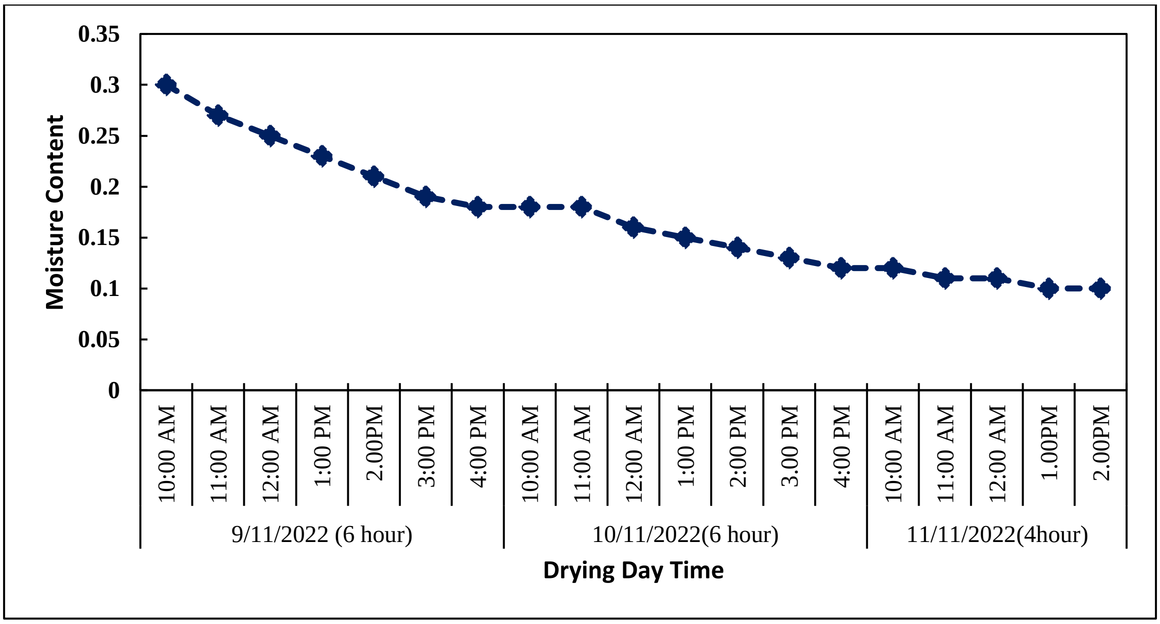

Figure 4.18: The Effect of the Drying Time on the Moisture Content of the Bombay Duck Fish.

In Figure 4.17 shows that the moisture content of Silver belly sample marine fish at 19/12/2021 was close to 0.3 which gradually decreased after drying on 22/12/2021 and in Figure 4.18 shows that, the moisture content of Bombay duck marine sample fish 9/11/2022 was close to 0.32 which gradually decreased after drying on 11/11/2022 the moisture content decreased to 0.1. From graphs it is also seen that the drying rate rapidly increases at earlier time and then slowly decreases as drying progresses. In, general, it is observed that drying rate reduces with time or with the reduction of moisture content. From the above figure it can be seen that it takes 21 hours for Silver belly fish and 16 hour for Bombay duck fish to dry naturally.

4.3 PROXIMATE COMPOITION AND BACTERIOLOGICAL ASPECTS

4.3.1 Proximate Composition of Microwave Dried Fish at Different Microwave Power and Air Velocity.

Proximate composition was analyzed to assess the nutritional qualities of dried Bombay duck marine fish sample, the percentage of moisture, protein, crude fiber, crude fat, ash, calcium, and phosphorus contents were calculated by the equ. (3.3, 3.4, 3.5,3.6, 3.7, 3.8, 3.9). The marine fish were dried in both 200 watt and 400 watts microwave power at different air velocity (0.10 ms^{-1}, 0.11 ms^{-1}, and 0.12 ms^{-1}). The test results of Bombay Duck fish are presented in Table-4.2, Figure 4.19 and Figure 4.20 it was found that for mw 200 watt and 0.10 ms^{-1} air velocity Crude fiber (0.25%), Crude Fat (16.67%), Ash (14.00%), Calcium (2.00%) and Phosphorus (0.67%) were higher but maximum protein (61%) was found for 0.12 ms^{-1} air velocity. From these results it was found that the microwave drying give best performance at 200-watt power and for exhaust wind velocity 0.1 m/s for Bombay duck fish. Standard plate count (SPC) method plate count agar media was used to calculate the total aerobic plate count, which was expressed as colony-forming units in one gram of sample (CFU/g) of the representative samples. The results of the study on bacterial load in microwave dried fish (Bombay duck) was found maximum 5.89 $\times 10^6$ CFU/g for microwave 200 w and exhaust air velocity 0.1 m/s

Table 4.2: Proximate Composition of Dried Bombay Duck Dry Fish at Different Microwave Power and Air Velocity.

Microwave drying power (W)	200			400		
Air velocity	0.10ms-^{1}	0.11ms-^{1}	0.12ms-^{1}	0.10 ms-^{1}	0.11ms-^{1}	0.12ms-^{1}
Moisture (%)	21.50	20.34	16.32	18.59	17.78	15.96
Protein (%)	58.17	59.10	61.00	56.55	57.75	58.80
Crude Fiber (%)	0.25	0.24	0.22	0.16	0.15	0.10

Crude Fat (%)	16.67	14.75	13.79	12.76	11.34	10.30
Ash (%)	14	13.55	10.30	8.70	9.50	9.00
Calcium (%)	2.00	1.89	1.97	1.40	1.50	1.46
Phosphorus (%)	0.67	0.59	0.56	0.40	0.43	0.41
Standard plate count (CFU/g)	5.89×10^6	5.12×10^6	5.44×10^6	4.90×10^4	4.79×10^4	4.66×10^4

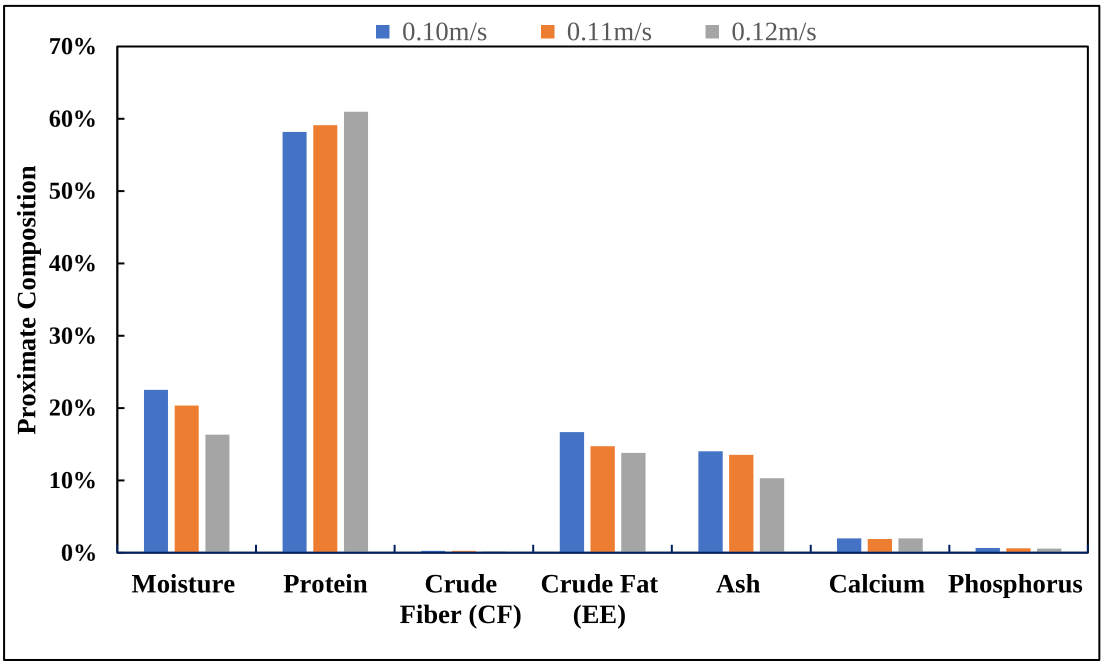

Figure 4.19: Proximate Composition of Microwave (200 W) Dried Bombay Duck Fish

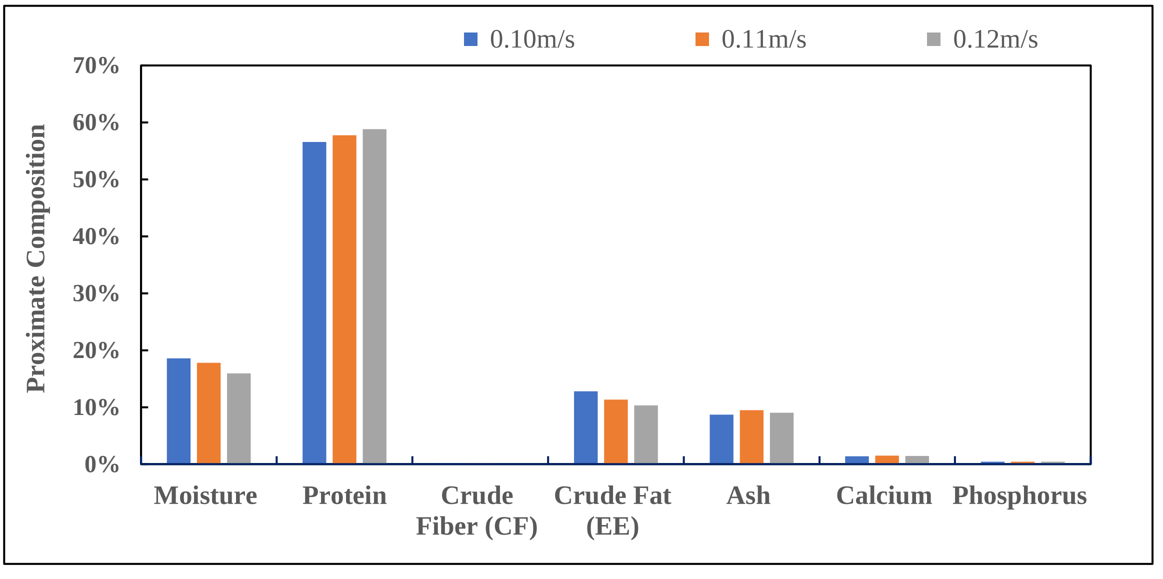

Figure 4.20: Proximate Composition of Microwave (400W) Dried Bombay Duck

The Table 4.3 and Figure 4.21 shows the proximate composition of Silver Jew fish protein, crude fiber, crude fat, ash, and phosphorus are found such as (86.88%, 0.94%, 6.25%, 26.56% respectively) for microwave watt 200-watt, and air velocity 0.10 m/s but Calcium, 5.01%, and Ash 27.97% was found higher for 400-watt, 0.10 m/s. In case of Silver Jew fish, the maximum proximate compositions were found better values when the microwave was run at 200w.The results of the study on bacterial load in microwave dried Silver Jew fish high value 4.96 $\times 10^5$ CFU/g (for 200w) less value 4.66×10^4 CFU/g (for 400w).

Table 4.3: Proximate Composition of Silver Jew Dry Fish at Different Microwave Power and Constant Wind Velocity (0.1 m/s)

Microwave drying power (W)	200	400
Moisture (%)	22.68	18.59
Protein %	86.88	82.56
Crude Fiber (CF) (%)	0.94	0.92
Crude Fat (EE) (%)	6.25	4.75
Ash (%)	26.56	27.97
Calcium (%)	5.00	5.01
Phosphorus (%)	2.00	1.90
Standard plate count (CFU/g)	4.96 $\times 10^5$	4.66×10^4

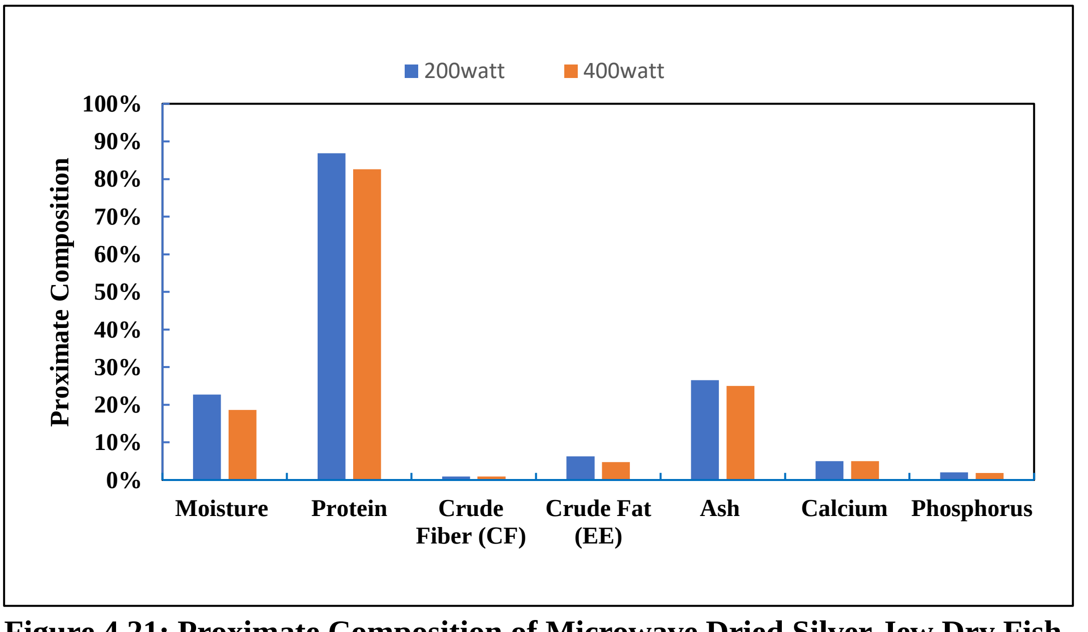

Figure 4.21: Proximate Composition of Microwave Dried Silver Jew Dry Fish.

The Table 4.4 and Figure 4.22 shows the percentage proximate composition of silver belly fish such as protein, crude fiber, crude fat, and Calcium (48.33%, 1.03%, 9.16%, 2.67% respectively) for microwave watt 200-watt, 0.10 m/s values were higher values but ash 8.87%, phosphorus 1.41% were found higher value for 400-watt, 0.10 m/s. The results of the study on bacterial load in microwave dried Silver belly fish was higher 8.9 $\times 10^5$ CFU/g for 200w then 400w (8.3 $\times 10^4$ CFU/g)

Table 4.4: Proximate Composition of Dried Silver Belly Fish at Different Microwave Power and Constant Wind Velocity (0.1 m/s)

Microwave drying power (W)	200	400
Moisture (%)	22.13	21.26
Protein %	48.33	46.38
Crude Fiber (CF) (%)	1.03	1.00
Crude Fat (EE) (%)	9.16	9.11
Ash (%)	7.76	8.87
Calcium (%)	2.67	2.60
Phosphorus (%)	1.40	1.41
Standard plate count (CFU/g)	8.9×10^5	8.3×10^4

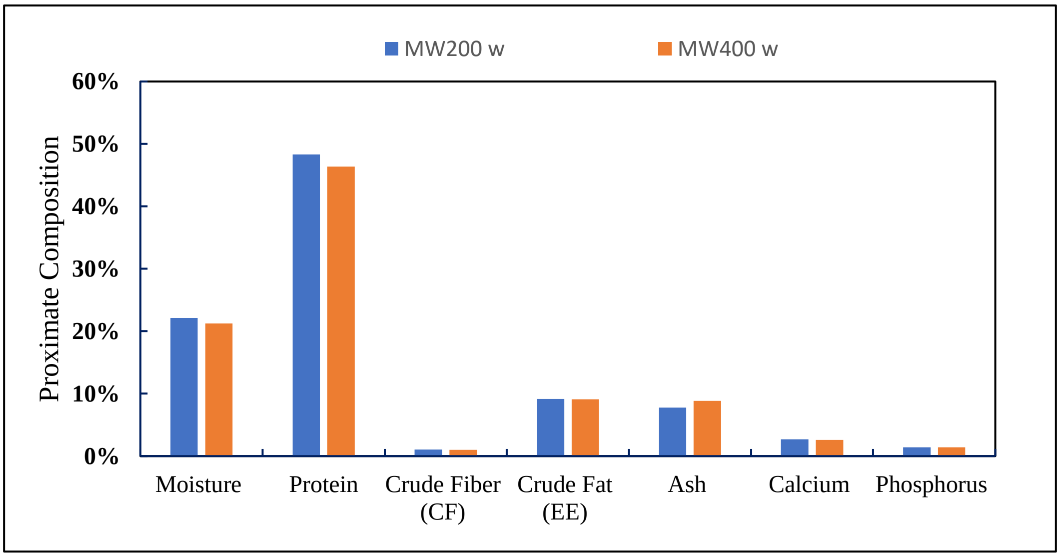

Figure 4.22: Proximate Composition Microwave Dried Silver Belly Fish.

The proximate composition of traditional dried fish and microwave (200w and air velocity 0.1 m/s) as compared which are given in the Table 4.5 and show in Figure 4.23 and Figure 4.24, it was found that Protein (58.17%), Crude fat (16.67%), Ash (14%), were higher in Microwave dried Bombay duck fish. And maximum Crude fiber (1.03%), Calcium (2.67%), and Phosphorus (1.40%) was found Silver belly fish. The bacterial load in microwave dried fishery product of Bombay duck fish and is 5.89×10^6 less than traditional 8.6×10^7 CFU/g. Similar results also found for silver belly fish 8.9×10^5 (MWD) < 5.6×10^8 Traditional dried sample.

Table 4.5: Comparative Proximate Composition of Traditional Natural Dry Fish and Microwave Dried Fish for Constant Exhaust Wind velocity (0.1 m/s).

Proximate composition	Bombay Duck Fish		Silver Belly Fish	
	Traditional Dried	Microwave Dried	Microwave Dried	Traditional Dried
Moisture	25	21.50	22.13	28
Protein	40.19	58.17	48.33	51.28
Crude Fiber (CF)	0.2	0.25	1.03	0.68
Crude Fat (EE)	6.05	16.67	9.16	13.57
Ash	16	14	7.76	8.88
Calcium	2.07	2.0	2.67	2.30
Phosphorus	0.49	0.67	1.40	1.27
SPC (CFU/g)	8.6×10^7	5.89×10^6	8.9×10^5	5.6×10^8

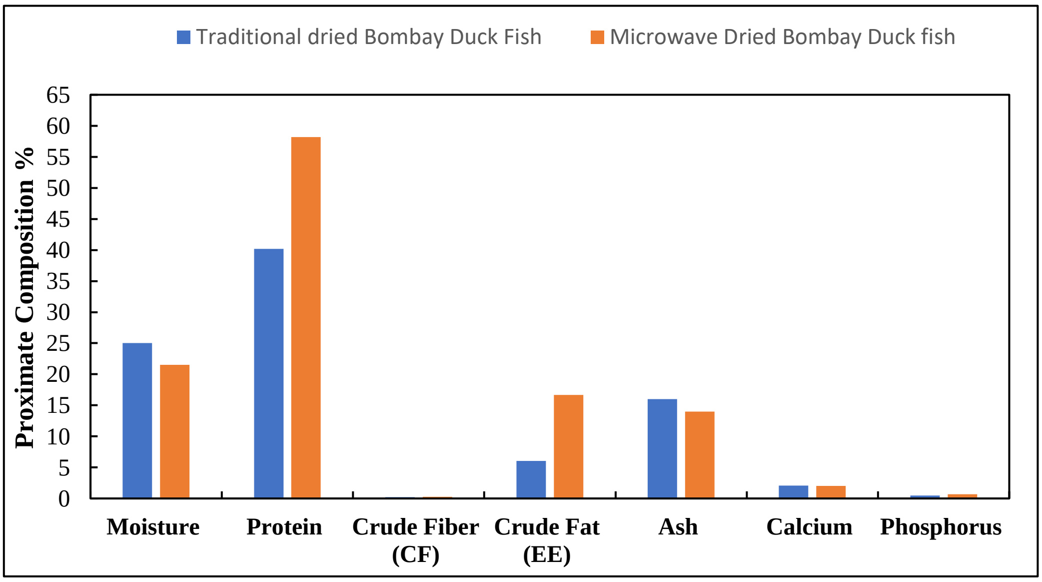

Figure 4.23: Comparative Proximate Composition of Traditional Natural Dry Fish and Microwave Dried Bombay Duck Fish.

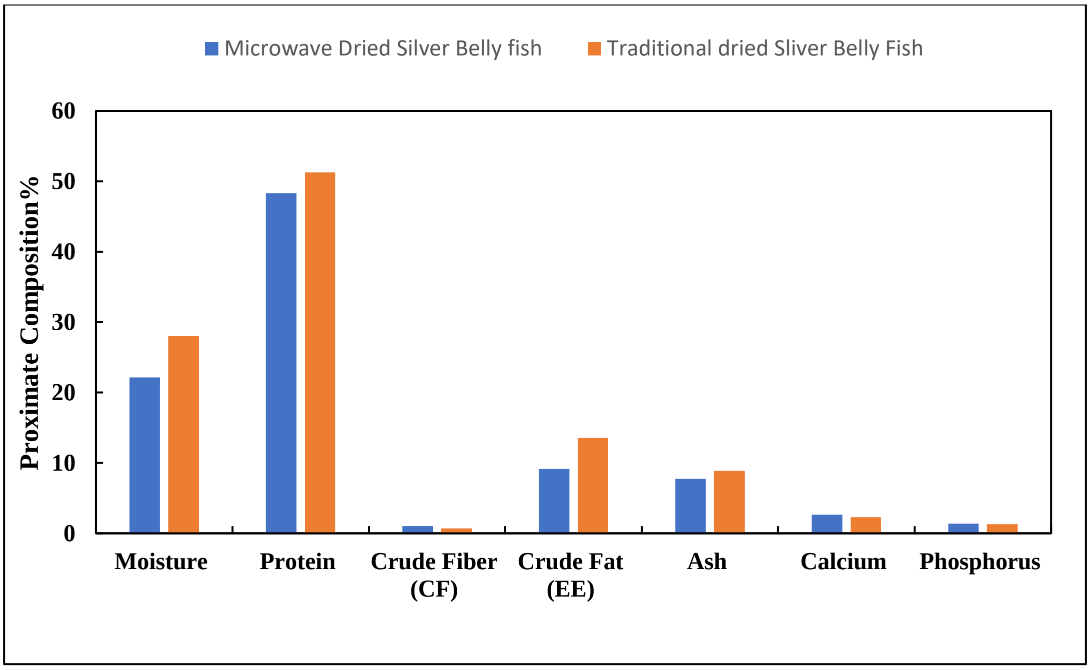

Figure 4.24: Comparative Proximate Composition of Traditional Natural Dry Fish and Microwave Dried Silver Belly Fish.

The moisture content and bacterial load in food products are closely related. Fish is an excellent medium for microorganism growth and reproduction. This is due to a variety of circumstances. One of them is appropriate moisture content. The heat used while drying significantly reduces the number of germs of various sorts. Heat drying normally kills all yeasts and most bacteria, but spores of some bacteria and molds usually survive. Bacteria, yeast, and mold cannot develop in environments with less than 20% moisture content. Microorganisms will not grow in dried fish if the drying procedure and storage conditions are suitable.

4.3.2 Comparison of Proximate Composition and Microbial Characteristics of Commercially Available Marine Dry fishes of Cox's Bazar.

The proximate composition analysis test of marine dry fishes (Bombay duck, Silver Jewfish) collected from Cox's Bazar to comparison with microwave (200w 0.10 m/s) dried fish.

Table 4.6 Proximate composition of Two different marine dry fish

Proximate Composition	Bombay Duck	Silver Jew Fish

Moisture (%)	Cox's Bazar dried fish	Microwave (200w)	Cox's Bazar dried fish	Microwave (200w)
	30.94	21.50	20.53	22.68
Protein (%)	38.67	58.17	58.63	86.88
Crude Fiber (%)	0.00	0.68	0.26	0.94
Crude Fat (%)	5.25	13.57	3.35	6.25
Ash (%)	24.58	8.88	18.62	16.56
Calcium (%)	1.10	2.30	3.40	3.00
Phosphorus (%)	0.45	1.27	1.70	2.00
SPC(CFU/g)	4.5×10^{6}	5.8×10^{6}	8.0×10^{6}	4.96×10^{5}

The percentage (%) of moisture, protein, crude fiber, crude fat, ash, calcium, and phosphorus content the test results are presented in Table 4.6. and Figure 4.25 and Figure 4.26. Compare among two fish's higher amount of Protein (58.17%), Crude fiber (0.68%), Crude Fat (13.57 %), Calcium (2.30%) and Phosphorus (1.27) were found in Bombay Duck fish dried with microwave 200w and 0.10 m/s but Ash (24.58%) was higher in cox's bazar dried Bombay fish. And a comparison between Jew fish maximum Protein (86.88), Crude fiber (0.94%), Crude fat (6.25%), Ash (24.58%), Phosphorus (2%) but the values of Calcium (3.40%) and Ash (18.62%) in microwave dried fish are lower than collected Cox's Bazar dried fish.

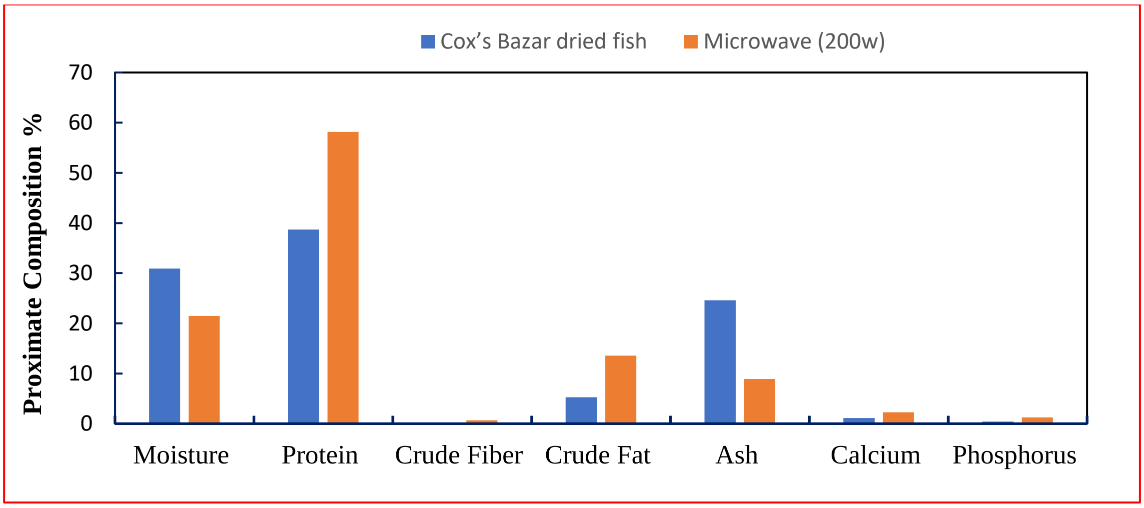

Figure 4.25: Comparative Proximate Composition of Traditional Natural Dry Fish (Cox's Bazar) and Microwave Dried Bombay Duck Fish

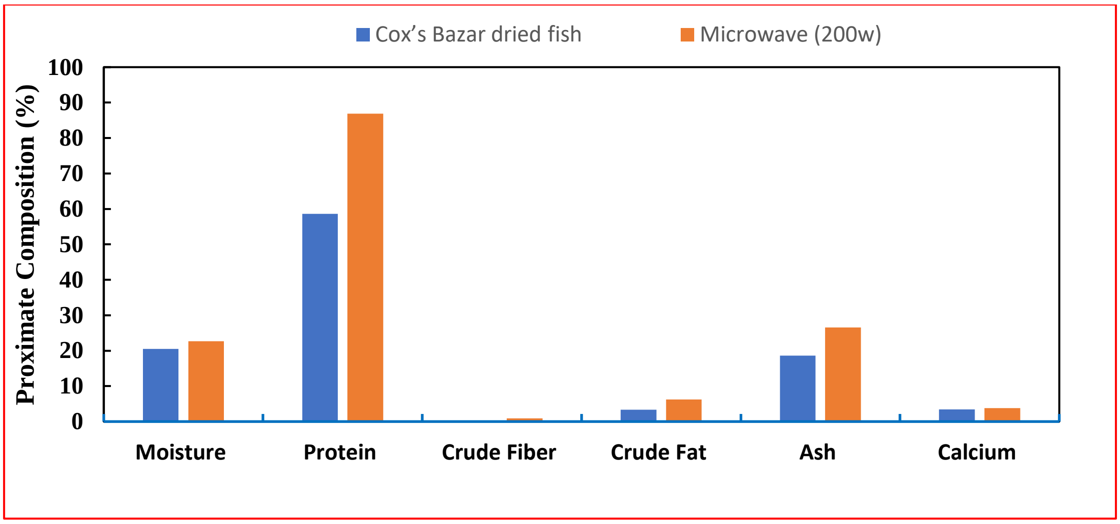

Figure 4.26: Comparative Proximate Composition of Traditional Natural Dry Fish (Cox's Bazar) and Microwave Dried Silver Belly Fish.

Standard plate Count (SPC) of traditional dried fish of Bombay Duck fish is 4.5×10^5 Which is lower than 5.6×10^7 and total bacterial load of Silver Jew fish was comparatively low 8.0×10^4 CFU/g.

4.4 PHYSICAL (organoleptic) QUALITY ASSESSMENT:

The organoleptic characteristics of dried Bombay duck, Silver belly, Silver Jew, fish from hot-air microwave, traditional and Cox's Bazar dried fish product are presented in Table 4.7. The quality of dried fish samples was based on color, odor, texture, insect infestation and broken pieces. The hot-air Microwave dried fishes have whitish and cream color with firm and elastic texture. The traditional dried fish were slightly grayish in color and has less firm and elastic in texture than hot-air microwave dried fish. Collected from Cox's Bazar and Saint Martine dried fish contain grayish to brown discoloration with soft texture and somehow fishy odor. There was no insect infestation and broken piece found in hot -air microwave drying and traditional sun drying fish in CUET campus but some infestation and broken pieces exhibit in the collected dried sample fish collected from Cox's bazar.

Table 4.7 Organoleptic Characteristics of Hot- Air Microwave, Traditional and Collected from Cox's Bazar Dried Fish.

Types of Samples	Color	Odor	Texture	Insect infestation	Broken Pieces	Overall quality

Hot- air Microwave dry fish	Whitish and Cream	Characteristics odor	Firm and elastic	No infestation	No broken pieces	Excellent
Traditional Dry Fish	Slightly Grayish	Characteristics odor	Firm and some loss of elasticity	No infestation	No broken pieces	Satisfactor y
Cox's Bazar dry fish	Grayish to dark	Rancid	Soft and loss of elasticity	Some infestation	Some broken pieces	Poor

(a) (b) (c) (d)

Figure 4.27: Bombay Duck Fish (a) Raw (b) Traditional Dried (C) Hot-Air Microwave Dried (d) Collected from Cox's Bazar

(a) (b) (c)

Figure 4.28: Silver Belly Fish (a)Raw (b) Traditional Dried (C) Hot-Air Microwave Dried Fish

(a) (b) (c)

Figure 4.29: Silver Jew Fish (a) Raw (b) Hot-Air Microwave Dried (c) Collected from Cox' s Bazar.

The physical condition of marine fish samples at different stage of drying by traditional, Microwave drying and collected from Cox's bazar are shown in the Figure 4.27, Figure 4.28. and Figure 4.29.

CHAPTER 5
CONCLUSIONS AND RECOMMEDATIONS

5.1 CONCLUSIONS

The main goals of this study are to develop an intelligent control system for pulsed microwave solar drying (PMSD) and to construct and operate a pulsed microwave solar drying system. By manipulating the drying conditions (such as air temperature, flow rate, RH, MW power, and intermittency), we can increase energy efficiency and improve product quality. We accomplished this using both a thorough analysis of the literature and the positive qualities of dried fish. Experimental research was used to validate the created PMSD setup. The major conclusions are:

1) The PMSD is found to be quit faster compared to natural convection drying due to intermittent application of Microwave.
2) The product's color and shape might vary greatly depending on the process conditions and structural modifications. Convection natural dried fish sample was less appealing than PMSD treated samples.
3) The developed PMSD set-up requires very lower amount of energy and also contributes significantly in reducing the environmental pollution.
4) Change of the quality during PMSD would help in decision making for an expected high value dried fish.

After drying the fish in hot air, it is dried in the microwave which takes much less time than drying in the sun. Prolonged drying times result in significant deterioration, blowfly infestation, contamination with soil particles, and the extensive use of various pesticides. We developed improved hot air Microwave drying has been created to improve the food quality of traditional dried fish and to prevent infestation and widespread contamination. The six components of Protein, Crude fiber, crude fat, ash, calcium, and phosphorus important for the human body have been compared to show that hot air- microwave dried fish had better quality than dried in the sun, and collected dried fish from Cox’s bazar. As seen from the proximate analysis of Microwave dried (200w and air velocity 0.1 m/s) Bombay Duck fish shows the Protein (58.17%), Crude fiber (0.25%), Crude fat (16.67%), Ash (14%), Calcium (2%), and Phosphorus (

0.67%) and Silver Jew Fish Protein (86.88%), Crude fiber (0.94%), Crude fat (6.25%), Ash (26.56%), Calcium (5%), and Phosphorus (2%) and Silver Belly Fish Protein (48.33%), Crude fiber (1.03 %), Crude fat (9.16 %), Ash (7.76 %), Calcium (2.67 %), and Phosphorus (1.40 %) .The values obtained show that the quality of microwave dried fish is better than that of natural dried fish. Total microbial load in this tested sample from natural sun drying for Bombay Duck fish (8.6×10^7 CFU/g), Silver Belly (5.6×10^8 CFU/g), and microwave dried Bombay Duck fish (5.89×10^6 CFU/g), Silver Belly (8.9×10^5 CFU/g) which is lower than sun drying. In terms of demand, the study opened up the way for the production and application of microwave-assisted hot air drying for marine fish in the near future.

5.2 Limitations

a) Industrial scale dryers have expensive initial costs.
b) For effective drying, a particular sample shape and size may be needed.

5.3 RECOMMENDATIONS

1. Improved microwave drying technique is better than traditional sun-dried technique which can be practiced commercially by the fish processors as it ensures high quality dried products. As the quality of dried fish deteriorates rapidly due to improper storage conditions, dry fish processors should ensure the best storage conditions to enhance the shelf life.
2. In this study, it only focuses on commercially available marine species Bombay duck, silver belly, silver Jew fish. Further research can be conducted on other commercially available fish. Vacuum packaging system, freezing temperature storage condition, TVB-N and heavy metal analysis should be included in further studies to investigate the changes of quality and shelf-life status of dried fish during storage. The limitation of this study is storage condition was not considered.

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A.1: Drying Parameters of Bombay Duck Fish at different Microwave Watt and Air Velocity.

Microwave Watt	**Temperature (^{O}C)**	**Weight of the sample (g)**	**Moisture Content MC (%)**	**Drying Rate (g/sec)**	**Air Velocity (m/s)**
400	32	101	0.66	--	0.10
	36	97	0.64	0.06	
	38	91	0.62	0.10	
	40	84	0.59	0.11	
	42	76	0.55	0.13	
	45	67	0.49	0.15	
	46	57	0.40	0.16	
	47	48	0.29	0.15	
	48.5	41	0.17	0.11	
	49.5	36	0.05	0.08	
	50	34	0	0.03	
400	32	101	0.65	--	0.11
	35	96	0.63	0.06	
	38.5	90	0.61	0.10	
	41	83	0.57	0.11	
	42	74	0.52	0.13	
	45.5	64	0.45	0.15	
	46	55	0.36	0.16	
	47.5	46	0.23	0.15	
	48	40	0.12	0.11	
	49.5	37	0.05	0.08	
	50	35	0	0.03	

400	32	101	0.67	--	0.12
	36	96	0.64	0.08	
	38.5	91	0.63	0.08	
	41	84	0.60	0.11	
	44	76	0.56	0.13	
	45.5	65	0.49	0.18	
	46	55	0.40	0.16	
	47	50	0.34	0.11	
	48	43	0.23	0.10	
	49.5	37	0.10	0.06	

Microwave Watt	**Temperature (^{O}C)**	**Weight of the sample (g)**	**Moisture Content MC (%)**	**Drying Rate (g/sec)**	**Air Velocity (m/s)**
200	50	33	0	0.05	0.10
	33	101	0.67	--	
	35	100	0.66	0.01	
	36	97	0.65	0.05	
	38	93	0.65	0.05	
	39	89	0.64	0.06	
	40	85	0.62	0.06	
	41	79	0.59	0.10	
	42	72	0.55	0.11	
	43	65	0.50	0.11	
	44	57	0.43	0.13	
	45	51	0.37	0.10	
	46	46	0.30	0.08	
	47	42	0.23	0.06	
	48	38	0.15	0.06	
	49	35	0.08	0.05	
	50	32	0	0.05	
200	32	101	0.66	--	0.11
	34	99	0.66	0.03	
	36	96	0.65	0.05	
	38	93	0.63	0.05	
	39	89	0.64	0.06	
	40	84	0.61	0.08	
	41.5	79	0.56	0.08	
	42	73	0.53	0.10	
	43.5	66	0.48	0.11	
	44	58	0.41	0.13	
	45.5	52	0.34	0.10	
	46	47	0.27	0.08	
	47	43	0.20	0.06	
	48	39	0.15	0.06	
	49.5	36	0.05	0.05	
	50	34	0	0.03	
	33	101	0.67	--	
	35	99	0.67	0.03	
	36	96	0.66	0.05	
	38	93	0.65	0.05	
	39	89	0.64	0.06	
	40	85	0.62	0.08	

Microwave Watt	Temperature (^{O}C)	Weight of the sample (g)	Moisture Content MC (%)	Drying Rate (g/sec)	Air Velocity (m/s)
200	41	79	0.59	0.10	0.12
	42	72	0.55	0.11	
	43	65	0.50	0.13	
	44	57	0.43	0.15	
	45	51	0.37	0.10	
	46	46	0.30	0.08	
	47	42	0.23	0.06	
	48	38	0.15	0.06	
	49	35	0.08	0.05	
	50	32	0	0.03	

A.2: Drying Parameters of Silver Jew Fish at Different Microwave Watt and Air Velocity

Microwave Watt	Temperature (^{0}C)	Weight of the sample (g)	MC (%)	Drying Rate (g/sec)	Air Velocity 0.1 (m/s)
200	33	389	0.30	--	0.10
	35	385	0.30	0.06	
	36	379	0.29	0.10	
	38	362	0.26	0.28	
	39	351	0.26	0.18	
	40	339	0.23	0.20	
	41	331	0.18	0.13	
	42	325	0.17	0.10	
	43	319	0.13	0.10	
	44	311	0.12	0.13	
	45	306	0.11	0.08	
	46	296	0.11	0.16	
	47	288	0.10	0.13	
	48	284	0.10	0.15	
	49	279	0.08	0.10	
	50	269			
	32	393	0.30	--	
	36	387	0.29	0.1	
	38	375	0.26	0.2	
	41	360	0.23	0.2	

Microwave Watt	**Temperature (^{0}C)**	**Weight of the sample (g)**	**MC (%)**	**Drying Rate (g/sec)**	**Air Velocity 0.1 (m/s)**
400	44	343	0.19	0.25	0.1 0
	45	323	0.18	0.28	
	46	309	0.13	0.33	
	47	298	0.12	0.15	
	48	295	0.11	0.08	
	49.9	277	0.10	0.07	

A.3: Drying Parameters of Silver Belly Fish at Different Microwave Watt and Air Velocity

Microwave Watt	**Temperature (^{0}C)**	**Weight of the sample (g)**	**MC (%)**	**Drying Rate (g/sec)**	**Air Velocity (m/s)**
400	32	301	0.38	--	0.10
	36	297	0.37	0.07	
	38	291	0.35	0.10	
	41	283	0.34	0.13	
	44	271	0.31	0.20	
	45	258	0.29	0.22	
	46	244	0.24	0.23	
	47.5	228	0.18	0.27	
	48	219	0.15	0.27	
	48.5	213	0.13	0.20	
	49	205	0.10	0.12	
	49.5	199	0.06	0.07	
	50	186			

Microwave Watt	**Temperature (^{0}C)**	**Weight of the sample (g)**	**MC (%)**	**Drying Rate (g/sec)**	**Air Velocity (m/s)**
200	33	310	0.38	--	
	35	306	0.38	0.06	
	36	300	0.37	0.10	0.10
	38	283	0.33	0.28	
	39	272	0.30	0.18	
	40	260	0.27	0.20	
	41	252	0.25	0.13	
	42	246	0.23	0.10	

	43	240	0.21	0.10	
	44	232	0.18	0.13	
	45	227	0.16	0.08	
	46	217	0.13	0.16	
	47	212	0.11	0.13	
	48	209	0.10	0.15	
	49	206	0.08	0.10	
	50	190		0.06	

A.4: Drying Parameters of Silver Belly Fish at Natural Sun Drying

Date	Time	Temperature (^0C)	Solar Radiation (W/m^2)	Wind Velocity (m/s)	Relative Humidity (%)	MC (%)
19/12/2021	10 am	23.6	450	1.4	78	0.29
	10.30 am	24.6	490	1.6	75	0.28
	11 am	25	500	1.5	73	0.27
	11.30 am	27	570	1.8	69	0.27
	12 am	28.6	610	1.9	60.6	0.27
	12.30 pm	30	596	1.5	63.8	0.26
	1 pm	29.6	516	1.9	51.9	0.26
	1.30 pm	28.7	470	2.2	65.9	0.25
	2pm	27.5	399	1.1	52	0.25
	2.30 pm	27	355	1.4	55.5	0.24
	3 pm	26.3	320	0.8	60.7	0.24
	3.30	25.2	210	1	65	0.28
	4.00 pm	24.3	184	1.3	68	0.23
	10.00 am	24	478	1.2	79	0.23
	10.30 am	24.3	528	1.1	73.8	0.22
	11.00 am	25.2	511	0.8	69.9	0.21
	11.30 am	29	550	1.9	62.8	0.21
	12.00 am	29.2	578	1.8	60.5	0.22

Date	Time	Temperature (^0C)	Solar Radiation (W/m^2)	Wind Velocity (m/s)	Relative Humidity (%)	MC (%)
20/12/2021	12.30 pm	27	522	2.2	63.6	0.21
	1.00 pm	26	320	2.5	65	0.21
	1.30 pm	25.6	228	3	65.6	0.19
	2.00 pm	26	254	3.3	64.6	0.19
	2.30 pm	24.9	195	3.2	66.2	0.18
	3.00 pm	23.9	188	3.4	66.6	0.18
	3.30 pm	22.9	170	3.2	67	0.17
	4.00 pm	22	165	3	68	0.17
21/12/2021	10.00 am	22.5	374	1.5	70	0.17
	10.30 am	24.5	430	1.8	65	0.16
	11.00 am	25.9	470	1.5	60.1	0.14
	11.30 am	25	530	1.7	65	0.14
	12.00am	24	586	1.9	69.9	0.13
	12.30 pm	25.4	230	1.5	50.5	0.13
	1.00pm	25.3	245	1.5	60	0.13
	1.30 pm	25.5	352	1.7	63.2	0.13
	2.00pm	24.3	280	1	63	0.13
	2.3o pm	24.6	230	0.8	64	0.12
	3.00 pm	23	220	0.9	63	0.12
	3.30 pm	23	200	1.2	62	0.12
	4.00 pm	22.6	170	1.5	63.6	0.11
22/12/2021	10.00 am	23	438	0.5	79.9	0.11
	10.30 am	24.5	517	0.8	77	0.11
	11.00 am	25.9	570	0.6	71.1	0.10
	11.30 am	26	560	1	70	0.10
	12.00 am	27	554	1.2	69.2	0.08

A.5: Drying Parameters of Bombay Duck Fish at Natural Sun Drying

Date	Time	Temperature (^{0}C)	Solar Radiation (w/m^2)	Air velocity (m/s)	Relative Humidity (%)	MC (%)
9/11/2022	10.00 am	25	800	1.1	57	0.32
	10.30 am	28	840	1.2	50	0.30
	11.00 am	29	900	1.1	52	0.29
	11.30 am	33	950	1.0	48	0.28
	12 .00am	34	980	0.8	40	0.27
	12.30 pm	35	940	0.9	38	0.27
	1.00pm	32	617	0.8	37	0.23
	1.30 pm	31	605	0.7	36	0.22
	2.00pm	30	550	0.9	38	0.22
	2.30 pm	30	541	1	43	0.22
	3.00pm	29	505	1.2	44	0.21
	3.30pm	28	488	1.4	47	0.21
	4.00 pm	27	400	1.5	48	0.20
	10.00 am	27	750	1.3	51	0.20
	10.30 am	29	798	1.2	47	0.19
	11.00 am	32	850	1.4	46	0.19

Date	**Time**	**Temperature (^0C)**	**Solar Radiation (w/m^2)**	**Air velocity (m/s)**	**Relative Humidity (%)**	**MC (%)**
10/11/2022	11.30 am	34	950	1.0	44	0.18
	12.00 am	33	930	0.8	42	0.17
	12.30 pm	32	850	0.9	40	0.17
	1.00 pm	31	750	1.0	41	0.16
	1.30 pm	30	679	0.7	42	0.16
	2.00pm	30	600	0.6	43	0.15
	2.30 pm	29	550	0.7	44	0.15
	3.00 pm	28	513	1.4	46	0.14
	3.30 pm	27	498	1.3	48	0.13
	4.00 pm	26	450	1.5	49	0.12
11/11/2022	10.00 am	27	720	1.3	50	0.12
	10.30 am	28	810	1.2	47	0.12
	11.00 am	29	875	1.4	48	0.12
	11.30 am	33	920	1.1	45	0.11
	12.00 am	35	950	0.7	44	0.11
	12.30 pm	34	875	0.9	42	0.11
	1.00pm	33	805	0.4	40	0.10
	1.30 pm	32	776	0.5	37	0.10
	2.00pm	31	713	1.1	36	0.08

A.6: Environmental Parameter of Nazirartek, Cox's Bazar at Different Date.

Parameters	Date	Time									
		AM				PM					
		8	9	10	11	12	1	2	3	4	5
Solar Radiation (w/m^2)	12/01/21	232	312	370	478	635	587	510	470	350	245
	16/01/21	228	318	349	448	624	546	471	450	328	212
Air Velocity (m/s)	12/01/21	0.9	0.9	1.0	0.8	0.8	1.2	1.2	1.2	1.5	1.6
	16/01/21	0.7	0.7	0.9	0.9	1.0	0.8	0.8	1.2	1.4	1.6
Temperature (^0C)	12/01/21	26.3	26.9	27.0	27.3	30.1	31.0	29.0	28.2	27.1	26.0
	16/01/21	26.0	27.0	27.5	27.9	31.3	31.0	30.5	27.8	26.0	26.0
Humidity (%)	12/01/21	66.0	65.0	62.0	65.9	55.1	56.0	58.6	60.0	68.0	69.0
	16/01/21	70.0	68.0	62.1	65.9	55.1	52.5	53.8	58.5	60.0	68.0